THE USE OF FORMAL METHODS FOR DECISION MAKING IN THE PLANNING PHASE OF HEALTHCARE FACILITIES

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THE USE OF FORMAL METHODS FOR DECISION MAKING IN THE PLANNING PHASE OF HEALTHCARE FACILITIES

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This thesis is dedicated to my family and to my husband Marcelo, who gave me both the love and support that I needed.

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LIST OF SYMBOLS AND ABBREVIATIONS

AHP	Analytical Hierarchy Process
CI	Criterion Indicator
CNE	Certified Nurse Educator
DGSF	Department Gross Square Feet
MCDA	Multi-Criteria Decision Analysis
NMSSS	Nursing Medication and Supplies Support System
QFD	Quality Function Deployment
RN	Registered Nurse
SPD	Supply Processing and Distribution

SUMMARY

The Pre-Project Phase of building construction manages the communication between client organization, user groups and designers. Disconnects and miscommunication in this phase may result in a product that does not fulfill the expectations of the parties involved. It is expected that the adoption of more formal methods can streamline the communication and improve its precision. Based on a literature review, a triage of methods is introduced: (a) a method for initial criteria management, supported by the EcoProP software (developed by VTT in Finland); (b) a method to rationalize and manage criteria in relation to the design organizational instruments, supported by the QFD ProP software (developed by VTT in Finland); (c) a method that supports multi criteria decision making, supported by a range of commercially available software tools. In order to assess the effectiveness of these tools they have been applied in the specific case of Pre-Project Phase of a healthcare facility. A Case Study on a concrete discrete decision problem is dealt with. It concerns the choice between a central medication room and patient room dispenser closets (also known as "Nurservers"). The Nurservers Case Study is used to evaluate the applicability of the proposed criteria gathering, ranking and decision methods in the Pre-Project Phase's daily practices. The claim that these rational methods increase efficiency, precision and satisfaction of the parties involved in this phase is investigated. The thesis evaluates how the introduction of rational methods benefits the communication between stakeholders.

CHAPTER 1

THE PROBLEM AND ITS BACKGROUND

Problem Statement

The Pre-Project Phase is the process of gathering, organizing, and interpreting information that defines the project's scope and foundation to the start of detailed design. The objective of the Pre-Project Phase is to produce a document that will assist a facility design team. Part of this information comes from the stakeholders, including, but not limited to, the owner, the users, the designers, and the construction manager. As a consequence, the stakeholders should be involved in the appropriate decisions to maximize the chances for a successful project.

The problem that this research addresses can be summarized as the difficulties involved in attaining efficient communication among stakeholders during the Pre-Project Phase. This is of special concern because different stakeholders bring unique, and sometimes rather different, technical backgrounds. Each stakeholder also has different priorities and expectations of the Pre-Project Phase. Disconnects and miscommunication while incorporating all of those distinct viewpoints may result in a product that does not fulfill the expectations of the parties involved.

Purpose of the Study

Formal methods for early control on decisions have the potential to advance communication between stakeholders and increase efficiency, precision and satisfaction during the Pre-Project Phase. Gibson and Pappas (2003) mentioned the critical importance of having team alignment for the project success. One of the ten critical issues presented by him as a positive influence of alignment is the effective use of planning tools such as checklists, simulations, etc. According to Gibson and Pappas (2003), the greatest advantage of using the tools is the communication incentive and acceptance of the approved decision outcome.

The ultimate objective of this study is to investigate a triage of methods that would improve the current process of the Pre-Project Phase by allowing earlier control over the outcomes of the design process. It aims to evaluate the applicability of the proposed methods in the existing Pre-Project Phase of healthcare facility daily practices regarding the methods' feasibility with respect to the claim that they increase efficiency, precision and satisfaction of the parties involved in this phase.

Background

Pre-Project Phase is a process which includes all activities until beginning of the detailed design (Gibson *et al*, 2006). A literature review of sources related to Architectural Programming, one of the Pre-Project Phase's, which are established references – Duerk (1993); Hershberger (1999); and Peña (2001) – presented different methodologies to approach the Pre-Project in general. The differences of methodology are related, for example, to the variety and dynamics of building types, amount of decision making already done, and differences among project situations (Popov, 1998).

A precise definition of the scope in this phase improves outcomes and satisfaction. Therefore, Pre-Project Phase is a crucial process that "must be performed consistently" and should involve "measured and consistent decision making" (Gibson *et al*, 2006). Understanding what happens in each stage of the Pre-Project Phase (Table 1) is important because one can identify which levels of decisions are made over time. There is no rigid structure for this phase, only common practices in the process of data gathering and decision making in order to better organize the levels of information.

Table 1: General Breakdown of the Pre-Project Phase according to Hershberger (1999).

Planning			*Programming*		
Financial feasibility study	Site suitability study	Master planning study	Programming for schematic design	Programming for design development	Programming for construction documents
			Architectural Programming		

The financial feasibility study will answer the main questions such as: is there a need for a new hospital? The site suitability study verifies, for example, if the necessary infrastructure exists and if the streets and utilities are available to support the proposed development. The master planning study will focus on how the site can be arranged. The programming for schematic design should specify general requirements that play a role to the client in a “building as a whole” level. The design development program introduces requirements that will affect specific functions of the “room level” (e.g. net area, relationships with other rooms). Finally, the construction documents phase specifies information that can be gathered by staff and manufacturers’ catalogs, and should not change the “overall formal and spatial organization” of the facility (Hershberger, 1999).

During the Pre-Project Phase risks are analyzed, schematic designs are produced, and decisions that will define the concept of the project are made. The outcome of these decisions and the project scope definition determine whether the project will be successful or not. According to Gibson *et al* (2006), there is a relation between problems in construction projects and inadequate or poor scope definition. A consequence of that is that final costs tend to be higher due to reasons such as rework, interruption on the project rhythm, etc. Gibson and Pappas (2003) also presented research results indicating that an effective Pre-Project Phase improves project performance and the predictability of that performance. This is a key phase in determining whether a project will ultimately support an organization's mission and meet the owner's requirements. Therefore, this phase is a prerequisite to prepare an effective scope of work for design.

In complex facilities, constant changes in the development situations generate a non-exact prototype and outdated guidebooks. Over time, previously known prototypes become obsolete and can be misleading (Popov, 1998). Planning for healthcare facilities, for example, could be obsolete in five years or less since responses to problems in these buildings have a limited lifetime, and many new technologies are being developed for their market that will affect space needs (Douglass, 1995).

The stakeholders of the Pre-Project Phase are those involved in the project and / or those that have influence in its objectives and outcomes (PMBOK® Guide, 2005). The involvement of stakeholders during the development of the project's scope could raise diverse issues regarding hierarchies and responsibilities (Gibson *et al*, 2006). During the Pre-Project Phase, the owner is constantly making strategic decisions for the scope of the project and taking risks.

Nowadays, the decision environment is more complex than ever before. There are many reasons for that, such as the desire to achieve multiple objectives at once, the many impacted groups with different values, the several decision makers that control the crucial aspect, the interdisciplinary professionals input, the consequences of many decisions that are not felt immediately, etc (Keeney, 1982). Moreover, some decision problems have a complex structure with great differences in perceived desirability between alternatives. Finally, there are no overall experts and stakeholders may need to get a justification about the decision (Keeney, 1982).

There are several benefits in applying a framework to organize the data to examine the decision problem. The objective of the implementation of a formal "decision making process" is to offer a structured way for solving problems and verifying that all factors are accounted for (Huovila, 2005).

CHAPTER 2

DECISION SUPPORT METHODS AND TOOLS

Based on the results of the literature review, three methods were introduced in order to streamline the communication and improve its precision: a method for initial criteria management, supported by the EcoProP software (developed by VTT in Finland); a method to rationalize and manage criteria in relation to the design organizational instruments, supported by the QFD ProP software (also developed by VTT in Finland); and a method that supports multi criteria decision making , supported by a range of commercially available software tools.

The first two methods, EcoProp and QFD ProP, have been tested in real cases and discussed in PeBBu conferences in Delft and Porto (Huovila *et al*, 2005). "PeBBu is a European Union funded `Thematic Network' dedicated to the Performance Based concept, as it applies to the Building and Construction Sector" (Szigeti and Davis, 2005). According to Huovila *et al* (2005) the results of the implementation were positive in both cases. This study combines EcoProp and QFD ProP methodologies with a multi criteria decision analysis technique in order to evaluate their efficiency in a discrete decision making problem.

Method for Criteria Management

Criteria management is a Pre-Project Phase data collection process based on stakeholders' design problem whose outcome will help further design decision making. In addition, the outcome will also be useful to the stakeholder as a tracking instrument of the decision outcome during and after the construction phase. This process aims to understand, model, and analyze the stakeholders' needs for the subject matter (Huovila, 2005). Overall, this process attempts to maximize the final product value.

Criteria management process seeks to introduce a list of criterion that covers the main aspects of the problem being addressed. Criterion is a statement giving the capability, characteristics, or quality factor of a product or process required to meet the needs and/or expectations of the stakeholders for an addressed subject and it assumes a value when it is incorporated into one or more criterion indicators (CIs).

Once the stakeholders are exposed to a set of criteria, they are required to provide a value level for them, according to their needs. Then, the information presented in the form of criteria indicators will elicit information from the stakeholder; remind the stakeholders of various issues; and/or inform the stakeholders of relevant aspects of the subject matter. Therefore, the stakeholders are asked to think in issues and to stipulate a goal for each issue.

Because it is not possible to fulfill all needs in an alternative solution (Keeney, 1982), the stakeholders are asked to rank their priorities further in the decision making process. Therefore, this method is focused in introducing the criteria and their correspondent values in order to identify the stakeholders' expectations. Then, once the expectations are identified, the designer teams are able to use the outcome as a guideline for their decisions.

EcoProP

EcoProP was developed by VTT, in Finland (Huovila, 2005). It is a flexible criteria management tool used to capture stakeholders' expectations and needs for the facility. The tool can be used either for a complex problem such as an entire facility of any type or for a discrete design problem, both during the Pre-Project Phase. Also, the tool's structure allows the stakeholders to add any comments or additional information that they think might be relevant for a specific criteria.

While developing a project, EcoProp presents a hierarchical structure on two main levels: the classification and the criteria. The classification can be structured through an existing classification, e.g. VTT ProP® Performance Classification (Huovila, 2005), or it can be developed by the criteria manager. Once the classification is defined, one can define the criteria.

While presenting the project in a work session (Figure 1), one can introduce the "check list" with all criteria to the stakeholders. Then stakeholders chose their expectations on the subject matter through the criteria indicators' value levels. The goal of the tool is to help the clients to "fulfill" their requirements and expectations (Huovila, 2005). After the work session, reports with the selected data can be generated for all stakeholders.

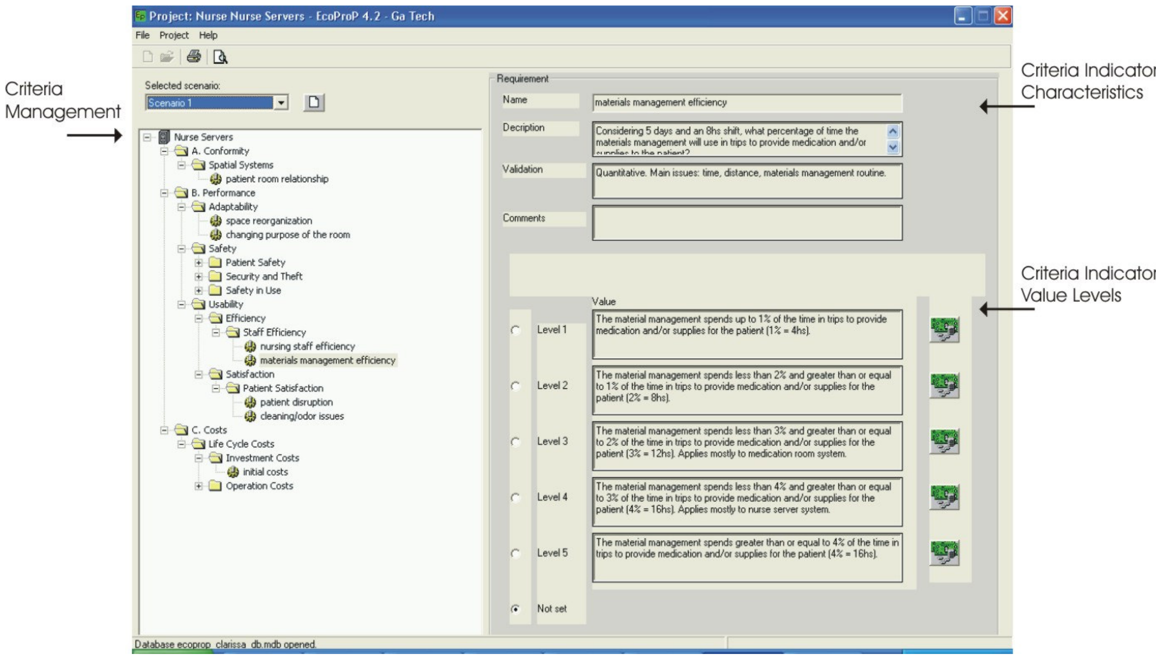


Figure 1: EcoProP Version 4.2.2's main layout.

Method to Rationalize Criteria in Relation to the Design Organizational Instruments

This method is based in the Quality Function Deployment (QFD). QFD was proposed late in the 1960's by Yoji Akao. Initially the method was developed to 'provide product developers with a systematic method for "deploying" the Voice of the Customer into product design' (Cohen, 1995). However, currently there is a range of different applications, e.g. early stages of facility design, services, etc.

The QFD method for traditional product design and production involves major steps that results in the construction of four matrices (Figure 2) (Cohen, 1995). The first matrix is called House of Quality and it is the basis of the QFD process. The process analyzed during this QFD stage is the product planning, which is the main subject of this study. According to Cohen (1995), one should customize the matrices to solve a particular problem, and is acceptable that one stops the process after completing the House of Quality matrix.

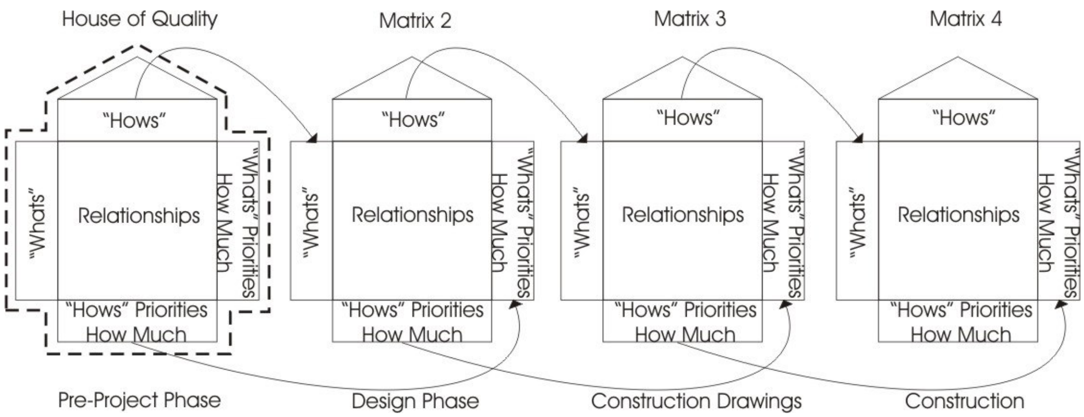


Figure 2: QFD overall sequence of matrices for AEC industry.
Source: Adaptation from Cohen, 1995; ReVelle, Moran and Cox 1998; and Huovila *et al*, 1997.

First, the "Whats" column in the matrix need to be constructed based on the stakeholders' needs. Therefore, the criteria are placed here (Figure 3). The second step is defining the "Whats Priorities" and is also called "quality deployment" (ReVelle, Moran and Cox, 1998). This step tries to answer the question "how important is the need to the customer?" and the result is a ranking of priorities. Cohen mentioned a five-point scale of importance is defined as: (1) not at all important, (2) of minor importance, (3) of moderate importance, (4) very important, and (5) of highest importance, and ReVelle, Moran and Cox (1998) suggested the Analytical Hierarchy Process (AHP) as a tool. Moreover, one can stop the process at this point and make an analysis with the highest criteria rankings.

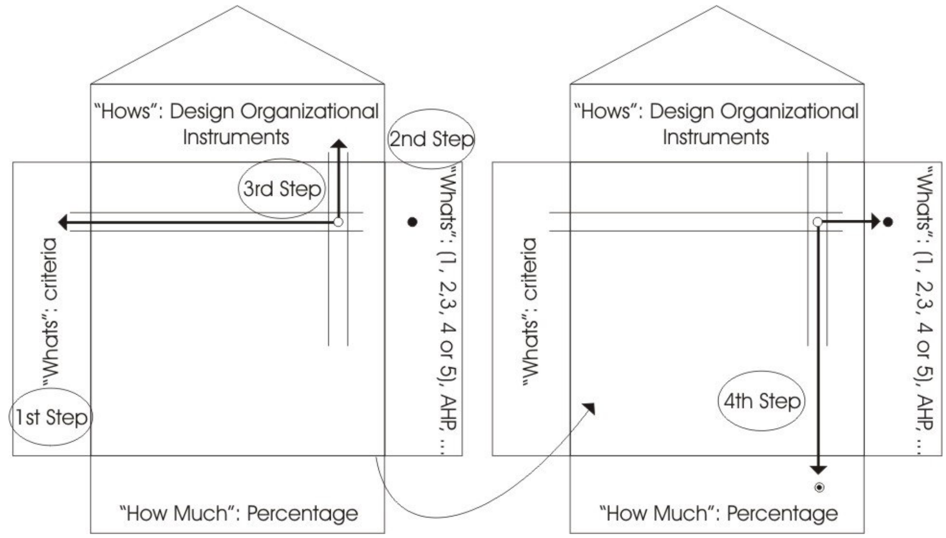


Figure 3: House of Quality.
Source: Adaptation from Cohen, 1995 and ReVelle, Moran and Cox, 1998.

The third step establishes relationships between "Whats" and "Hows" by the stakeholders and this step is also called "function deployment" (ReVelle, Moran and Cox 1998). This relationship can be defined as a strong relationship (9), a medium relationship (3) and a weak relationship (1). When there is no relationship, no number is computed. Then, one can identify the Design Organizational Instruments that are crucial to the most important criteria (step four). The Design Organizational Instruments are statements which define how the design solution could be.

QFD also allows a competitor analysis, an evaluation of competing alternatives, during the second step, quality deployment. However, even though QFD aims to prioritize the stakeholders' needs, the isolated ranking system through "an arbitrary scale is a process vulnerable to many biases" (ReVelle, Moran and Cox 1998). In addition to this critique, Huovila *et al* (1997) reported as an experience from his QFD application process that "the sensitivity of the method and minor variations in weight percentages causes uncertainty". Hence, as ReVelle suggested, an alternative would be the use of the hierarchy level paired evaluation approached by the AHP.

QFD ProP

QFD ProP was developed by VTT, in Finland (Huovila, 2005). It was suggested to be used as a following phase, after the EcoProP process (Huovila *et al*, 2005), and its approach consisted of two steps. The criteria indicators previously selected in EcoProP, should be organized in the rows of the matrix (Figure 4). Even though the literature names these criteria, they should rather be named criterion indicators due to the fact that they have values associated with them.

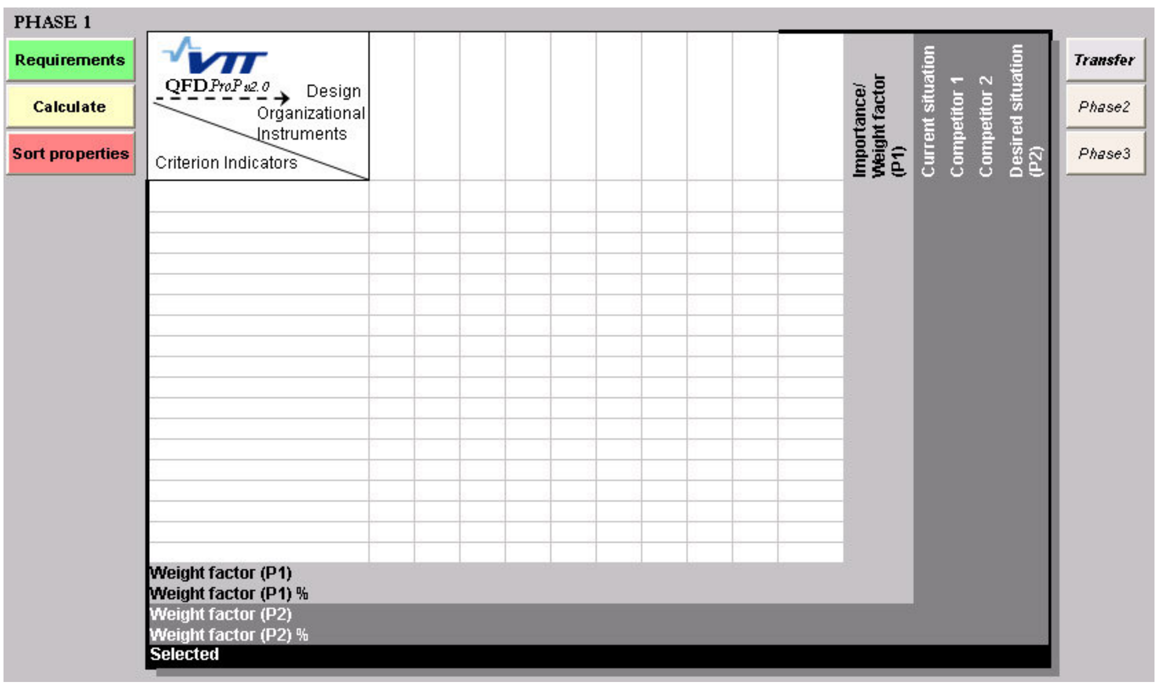


Figure 4: QFD ProP Version 2.0 main layout.

As a first step, the stakeholders rank, through a weight scale from 1 to 5, the CIs ("whats") in relation to their importance. The ending result is a column named importance factor. The next step is to establish a functional relationship between the CIs and the Design Organizational Instruments ("hows") through scale of importance. The numbers are 0, 1, 3, and 9, with 0 meaning no relationship. Then, the number that corresponds to each relationship is multiplied by the importance factor of the CIs, and the sum of all these correlations is computed along the bottom of the matrix. The most important Design Organizational Instruments are then identified.

Method for Decision with Multiple Criteria

As mentioned in Chapter 1, there are many reasons for the complexities of the decision environment. Negotiating the decision problem is complex due to its many objectives, criteria, and alternatives. Moreover, difficulties arise when complexities increase. The consequences of criteria judgment are not clear and the judgment process is most of the time a personal rating. Different participants may have different answers based in different values, none of them right or wrong (Keeney and Raiffa, 2002).

In 1976, Keeney and Raiffa published the book “Decisions with Multiple Objectives: Preferences and Value Tradeoffs”, which proposed the Multi Criteria Decision Analysis (MCDA) approach based in the Decision Theory. “MCDA is both an approach and a set of techniques”, and aims to provide a score for alternatives with the objective of structure the decision making process, however, “not to take the decision” (Dodgson *et al*, 2000). Therefore, analysis of the decision problem introduces and processes a formal subjective judgment during the alternatives’ evaluation (Keeney, 1982).

Current MCDA procedures structure the decision problem in a sequence of steps that provide clarity for those that will make the decision. The MCDA starts when its aims and parties are identified. The parties are composed by three main players: the Decision Maker, who makes the decision and assumes the consequences, the Decision Analyst, who facilitates the process, and the Stakeholder, who will be affected by the consequences of the decision (Huovila, 2005). The next step is to develop the decision analysis system based on the exchange of information provided by the parties. Then, objectives and criteria, which express the means in which the alternatives create value, are identified (Dodgson *et al*, 2000).

Nevertheless, a structured process is necessary in order to organize the alternatives and criteria. Authors – Howard, 1988, Dodgson *et al*, 2000, and HUT, 2002- suggested the adoption of the value tree structure, also hierarchy of criteria, based on Decision Theory (Dodgson *et al*, 2000). The value tree is mentioned as an efficient framing process that provides benefits such as an aid to avoid criteria redundancy and duplication, a better understanding of the problem and the values that affect the decision, helps visualizing the criteria in the context of the problem and checking whether they are necessary, and also makes easy the criteria weight calculation. An example of criteria hierarchy approach is presented in the EcoProP criteria management structure (left side of Figure 1), in the first session of this chapter.

Once the parties agree on the decision problem organization, the subsequent step is to weight the criteria in relation to each alternative and to rank their importance in relation to the decision problem. Therefore, this process means weighting both the differences between options and "how much that difference matters" (Dodgson *et al*, 2000). Hence, a consistent weighting scale should be used in order to compare different criteria subjects. After the results are calculated, questions such as "what if…" are common and an analysis of it should be made in order to provide an understanding of the consequences of the decision. This can be made through a sensitivity analysis. This analysis was introduced by advances in the decision analysis through procedures on systems engineering developed during World War II (Howard, 1988). The sensitivity analysis aims to evaluate how the model is sensitive to changes and clarify conflicts of interests between stakeholders.

There are different decision techniques when involving multi criteria, and this will depend on the type of decision, how the technique deals with the data provided, the time available for the analysis, the nature of the data available, the analytical skills of the stakeholders, etc (Dodgson *et al*, 2000). All techniques that approach the MCDA present criteria and alternatives in its structure, and require subjective judgment to deal with the problem complexity. This judgment is mainly a numerical analysis by scoring the most preferred options higher on the scale. In addition, they try to approach the problem in a consistent way. However, they differ processing the data (Dodgson *et al*, 2000). The Case Study presented in Chapter 3 has three main characteristics: there are a limited number of alternatives, uncertainty and risk are not formally being considered, and the criteria are formally independent of each other. Therefore, techniques based in the linear additive model are suitable to this approach.

Linear additive models are the basis of the MCDA; they combine individual values into one overall output. This is done with multiplications of each value's score on each criterion by the weights of the criteria, and then summing these weighted scores. The AHP also uses a linear additive model, but the weights and the scores obtained by alternatives are based, respectively, on paired comparisons of criteria and alternatives (Saaty, 1994). Thus, the decision maker compares criteria in pairs through a series of questions to calculate their importance in relation to their priorities.

Analytical Hierarchy Process (AHP)

The AHP is one of the most frequently applied multi criteria decision techniques (Dodgson *et al*, 2000). This method was developed by Thomas Saaty in 1970's and uses the stakeholders' ability to rank the criteria in relation to each alternative and to rank their importance in relation to the decision problem through a paired comparison.

The starting process has the similar hierarchy of criteria described in the previous section. After the various elements of the decision problem are specified, with the main goal, levels of criteria, and alternatives, these elements are compared in each level in pairs (Saaty, 1994). The comparison is based in the stakeholders' experience and knowledge while interpreting the data through the scale presented in Table 2. The value assigned for the comparison is the reciprocal ranked. For example, criterion X is judged strong plus for a decision in relation to criterion Y, then, the value for criterion Y relative to criterion X is 1/6. After all comparisons are done, a weight is computed for the alternatives and they are evaluated through the linear additive model for MCDA (Dodgson *et al*, 2000).

Table 2: AHP Scale of Comparison.

Scale	Verbal Statement	Explanation
1	Equal Importance	Two activities contribute equally to the objective
2	Weak	
3	Moderate Importance	Experience and judgment slightly favor one activity over another
4	Moderate plus	
5	Strong importance	Experience and judgment strongly favor one activity over another
6	Strong plus	
7	Very strong or demonstrated importance	An activity is favored very strongly over another; its dominance demonstrated in practice
8	Very, very strong	
9	Extreme important	The evidence favoring one activity over another is of the highest possible order of affirmation

Source: Saaty, 1994.

Comparison of Six Commercially Available Software Tools

There are a range of tools that support multi criteria decision analysis available in the market that use the AHP approach. Six tools were selected and tested using trial versions available in the web. The tools' features were compared based on the versions provided and the results of this comparison are shown in Table 3. The technical comparison was rated qualitatively based on three levels: (-) means poor/one single option, (+/-) means acceptable, and (+) means excellent/two or more options. In case that the tool doesn't present the given feature, no rating was recorded. Note that it is possible that the full version contains features that are not presented in the tested versions. For example, even though the full TESS software version seems to have participants' tools, the free trial allows only an exploration of a given example, and a consequence of this is the impossibility of performing a participants' tools evaluation. Also, remote features through internet and/or network were not evaluated because most of the tools' available were evaluation version and did not include the web-based version or group version. Therefore, this feature was not tested for most of the tools' identified in the Table 3.

Table 3: Comparison of Selected Tools which Support AHP.

Features/ Tools	**CDP* 3.04 Student Version**	**Web-Hipre Version 1.22**	**Expert Choice® 11 Trial Version**	**Decision Lens™ Suite v1.6.17**	**Logical Decisions® V6.0 Trial Version**	**TESS** Version 6.02.0138 Free Trial**
Friendly Decision Hierarchy	+	+	+/-	+/-	+/-	+/-
Techniques Assessment Options	+	+	-	-	+	+
Weighting/Ranking Process	+	-	+/-	+/-	-	+/-
Friendly Interface	+	-	+/-	+	-	-
Inconsistency Tool			+	+		-
Dynamic Graph and Sensitivity Analysis	-	-	+	+	-	-
Individual Participants Weighting Process		+/-	+	+		
Individual Participants Weight Value			+	+		
Resources Allocation Tool				+		
Report Process	+/-	-	+	+		+/-
Access to Software	+	-	+/-	+/-	+/-	+/-

* Criterium® Decision Plus®

** Technology Evaluation Support System

Analytical Hierarchy Process through Decision Lens™ Software

Decision Lens™ Suite v1.6.17 software (Figure 5) was selected among the others to be applied in the pilot testing based on the characteristics of the Case Study (Chapter 3) and results which are presented in the Table 3, in the previous section. The software supports only the AHP weighting method and enables integration of participants' individual weightings through an arithmetical mean. One fact worth noting was that this particular tool was not mentioned in any of the references consulted as part of this study.

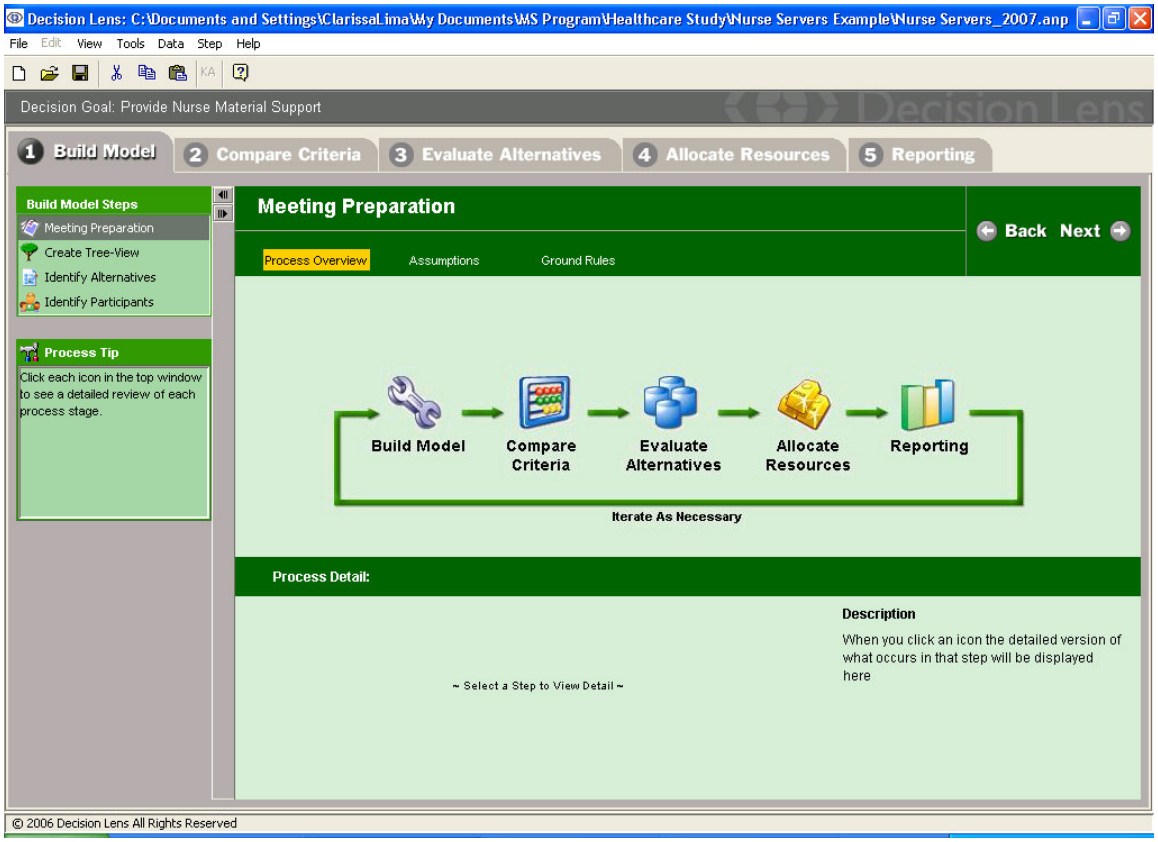


Figure 5: Decision Lens™ Suite Version 1.6.17 main layout.

First, the model is built hierarchically through a decomposition of the overall goal of the decision, the criterion indicators, and finally, the alternatives at the bottom of the hierarchy. Note that these are the CIs previously selected and ranked during the QFD method in the quality deployment phase. In addition, Decision Lens software allows participants identification. Therefore, this tool allows both a consensus and individual alternatives ranking.

Second, the participants set priorities between the CIs in relation to the decision goal through a paired comparison. The comparison is presented by both a quantitative and a qualitative fixed values scale. Please observe the example provided in the Figure 6.

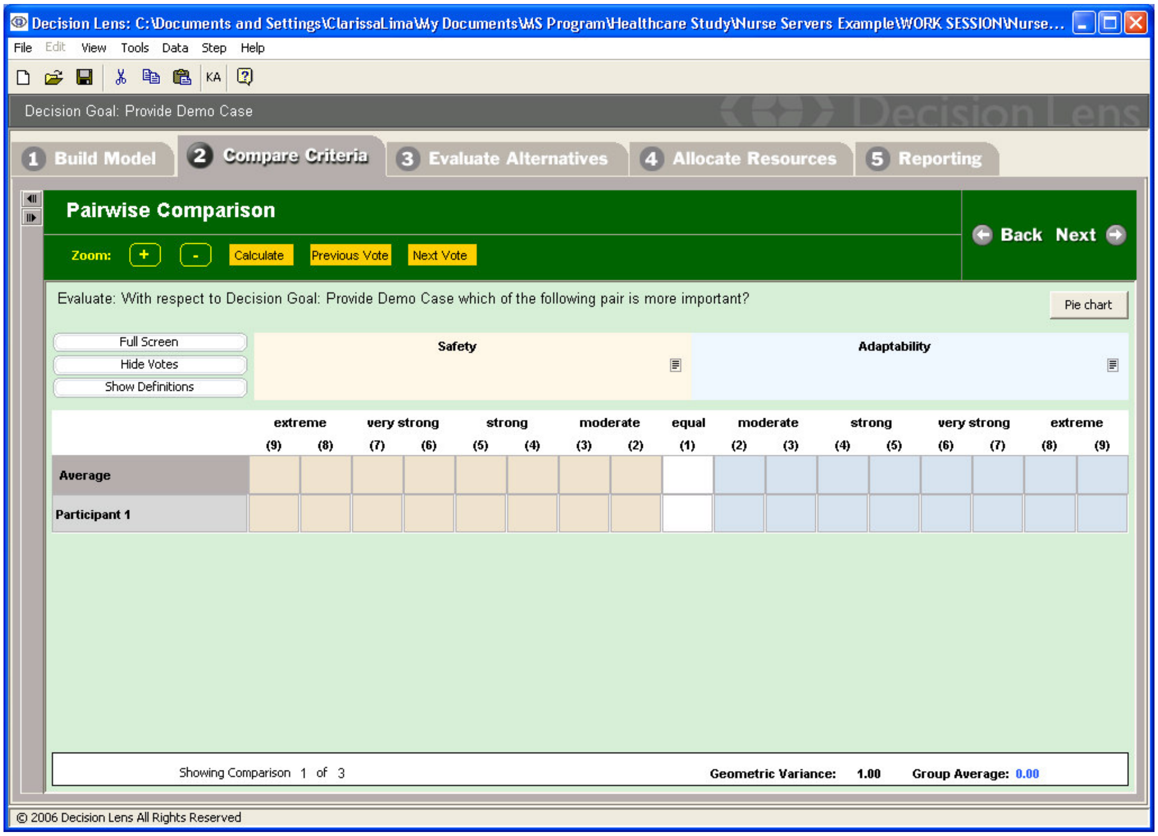


Figure 6: Decision Lens™ Suite Version 1.6.17 CIs comparison.

The quantitative scale is composed by numbers from one, in the center of the X-axis, to nine on each axis' extreme. The qualitative scale is composed of simplified verbal statements representing the numbers of the quantitative scale. In addition, the alternatives are weighted through a similar process, by establishing relative importance through their comparison in relation to each CI (Figure 7).

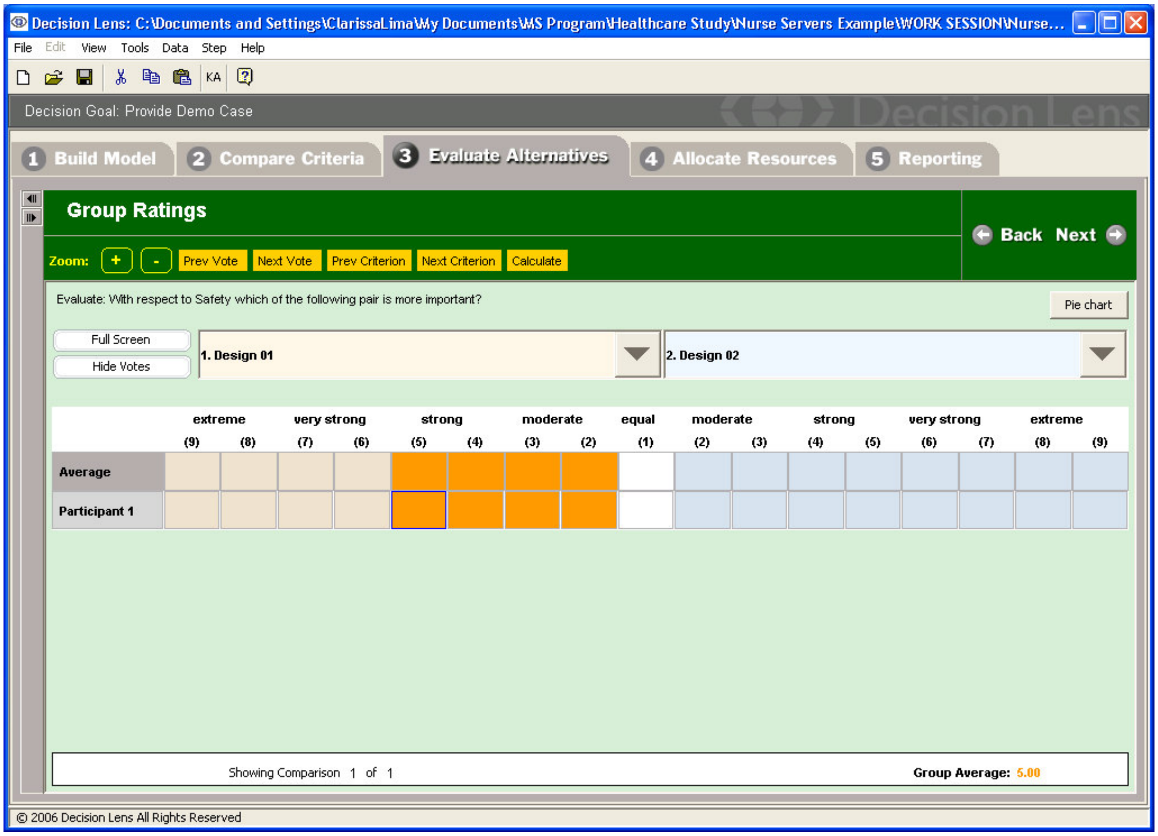


Figure 7: Decision Lens™ Suite Version 1.6.17 alternatives comparison.

Finally, the participant can analyze the decision through a dynamic sensitivity graphic in order to understand the different scenarios in which CIs affect alternatives and validate the results (Figure 8).

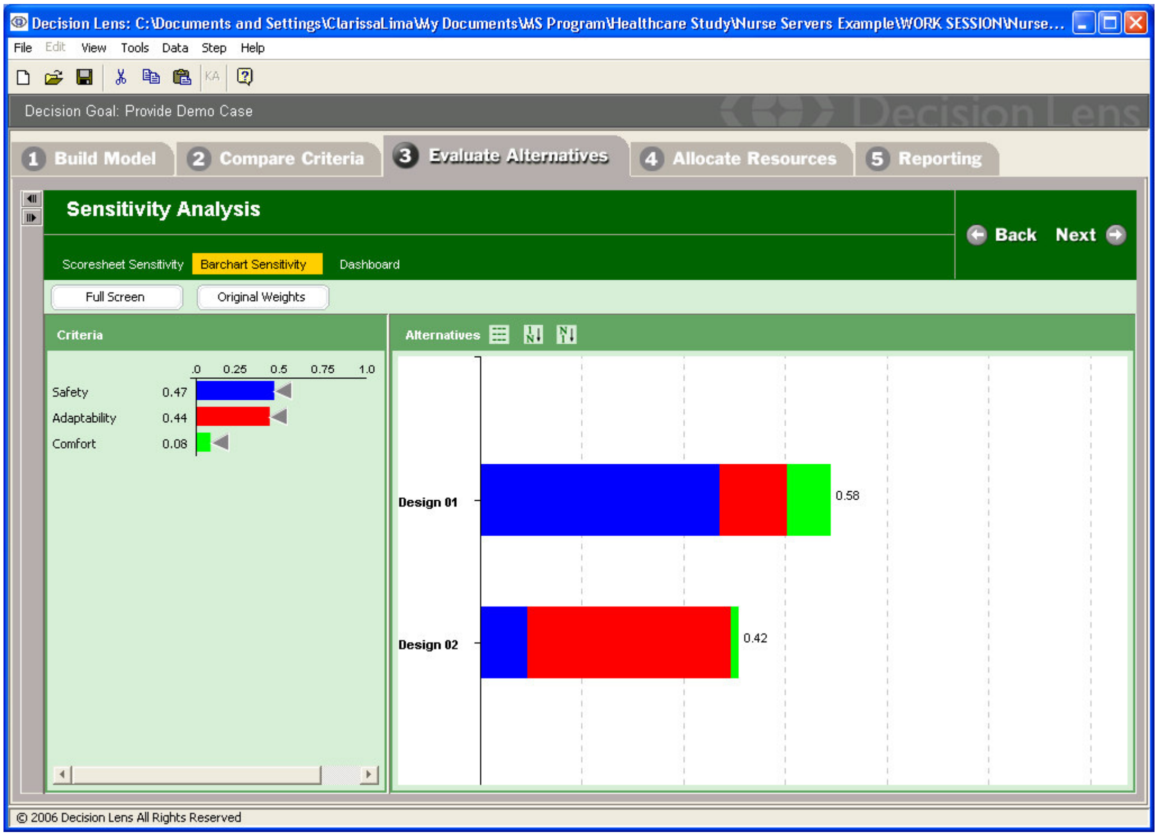


Figure 8: Decision Lens™ Suite Version 1.6.17 sensitivity analysis.

Summary of Chapter 2

A triage of methodologies for Pre-Project Phase decision support was introduced based on literature review followed by tools. The objective of their implementation was to offer a structured process for solving problems during this phase and verifying that aspects that play a role during the decision are accounted for.

The first method approaches initial criteria management, supported by the EcoProP software (developed by VTT in Finland), and the process seeks to introduce a list of criteria that covers the main aspects of the problem being addressed. The main application of this method is to capture stakeholders' needs and expectations for the future facility. The second method rationalizes and manages criteria in relation to the design organizational instruments. This method is based in the QFD methodology and is supported by the QFD ProP software (developed by VTT in Finland). The main application of this method is to identify stakeholders' needs for the facility through a ranking process.

Finally, the third method is the multi criteria decision analysis (MCDA). MCDA structures the decision problems in using a sequence of steps in order to clarify the decision process for the stakeholders. This methodology requires a decision problem with a limited number of alternatives and with criteria formally independent of each other. Then, this methodology determines the overall stakeholders' preferences among the alternative options, where the options accomplish several objectives. The technique selected to support this methodology is the Analytical Hierarchy Process (AHP). Through this technique the participants weight the criteria's importance in relation to the decision problem through a paired comparison, and then weight the alternatives in relation to each criterion. After an evaluation of a range of software that support AHP (trial versions) available in the Internet, the Decision Lens™ Suite was selected to pilot test the case study.

CHAPTER 3

INTRODUCTION TO THE CASE STUDY

Case Study Problem Context

The architects involved in the Houston Medical Center new bed-tower project and their clients were faced with a decision problem regarding having centralized or decentralized medications, supplies, and linen storage. The design alternatives, based in these two system approaches, are the traditional design of independent rooms for the specific functions or the design of a cabinet for each patient (Figure 9), called Nurserver, supported by the traditional design.

Figure 9: Nurserver from corridor side and from patient room, respectively.
Source: Courtesy from Hamilton Medical Center, Dalton.

The concept of the Nurserver rose from a need for efficient nursing operation. Until the 1950's the nursing units were increasing in size and the nurses were spending "at least 40% of their time walking" (Kobus *et al*, 2000). After World War II healthcare facilities faced a revolution on their design with the introduction of the Hill-Burton Act, which gave incentive to studies such as The Yale Traffic Index. The goal was to reduce nurses' trips and travel time and increase the average patient care. Then, in the late 1970's a new approach to medication and supplies storage design was introduced based on Friesen design guidelines for health planning (James and Tatton-Brown, 1986). Friesen proposed the use of a two-way storage cabinet for a particular patient, called Nurserver, so that the nurse could have "what she wanted where she wanted when she wanted" (James and Tatton-Brown, 1986).

However, some facilities that adopted the Nurservers in the past are no longer using them and/or are not requiring them when doing renovations. Reasons for that were identified during the interviews with healthcare practitioners and are related mainly to reductions in costs of restocking medications, supplies and linen and also improvements in the patient room area. Examples of facilities that no longer use some or all of their Nurserves are the Emory Healthcare facilities and the Athens Regional Medical Center. Thus, there are many factors that contribute for this decision problem, and the question is: How can one make a rational analysis of the decision problem for the Houston Medical Center?

Case Study Methodology

Initially, a meeting was established with the architectural project manager in order to gather information about the decision problem and to identify the aspects that played a role in the decision making process. The practitioners' expertise was crucial to understand the problem complexity.

After having identified the main criteria, an extensive information gathering through diverse sources such as published literature, the Internet, and magazines was conducted. This exercise was supplemented by a questionnaire (see Appendix A) and interviews that were developed to gather information from professionals with expertise in the subject matter. This questionnaire covered information regarding the use of centralized and decentralized nursing material support system. Following this information gathering process, the main criteria were given values through the development of criterion indicators.

Finally, the structure of the decision problem was organized and framed. The information gathered was computed in the tools in order to make the decision making session faster. Because of the tool's flexibility, any additional information that was not considered previously can be added in the decision process. This allows interaction between stakeholders and a decision making targeted to a particular case.

Data Collection and Questionnaire Interpretation

Relevant data collected through published literature, the Internet, and magazines was very scarce and some of them dated from the 1970's. To compensate for this, a questionnaire was developed based on the little information that was available. Therefore, the main information used in the study was gathered through questionnaire and interviews. Initially, a site visit to Hamilton Medical Center was conducted in which two professionals were interviewed. Then, questionnaires were distributed to two other hospitals.

At the end of the study, only three questionnaires were returned, one from Hamilton Medical Center, Dalton GA, and two from Athens Regional Medical Center, Athens GA. After receiving the questionnaires there was a need to interview participants in order to clarify some questions. The results of the questionnaires revealed that there were inconsistencies between some answers, and there were similarities among others. An analysis of the results is presented in the following paragraphs.

First, the Nurserver is a device whose functional use is related to the organizational structure of the unit/department in which it is inserted. Nurservers can store different items and their choice depends on the unit's administration. Another important conclusion is in relation to who is in charge to restock the linens in the Nurserver. Depending on the facility administration, this could be done by nurses or by technicians. In addition, questions regarding security and theft were answered with different values even though the Nurservers had the same security system.

Overall, the questionnaire was not an effective method for information gathering because of both the complexities of the nursing medication and supplies support system (NMSSS) and the difficulties involved in analyzing the questionnaires' results. Also, there were inconsistencies related to the number of trips reported by the nurses. Results through the interviews indicated that there is a relation between the numbers of trips for medication purposes and the patient type, surgical and medical, but these results were not conclusive.

Summary of Chapter 3

This chapter introduced a Case Study on a concrete discrete decision problem concerning the choice between a central medication room and patient room dispenser closets (also known as “Nurservers”). The concept of the Nurserver arose from a need for efficient nursing operation but facilities that adopted it in the past are no longer using them and/or are not requiring them when doing renovations due mainly to reductions in costs of restocking the medications, supplies and linen. Therefore, the stakeholders' needs and expectations should be properly identified in order to support and clarify the decision process.

A methodology to structure the problem is defined based in information gathering with experts in the subject matter and stakeholders involved in the decision problem. The main criteria were identified during a series of meetings with the architectural project manager. The most important source of information was gathered through questionnaires and interviews with key staff from Hamilton Medical Center and Athens Regional Medical Center. Finally, given the complexities of the nursing medication and supplies support system, inconsistencies on the data provided on the questionnaires required further clarification with the respondents.

CHAPTER 4

CRITERIA IDENTIFICATION

Introduction to the Criteria

This section presents a set of nine criteria for nursing medication and supplies support system (NMSSS). The main criteria and criterion indicators (CIs) were identified in the first two meetings with the architectural project manager. The development for all of these criteria, the criterion indicators, is presented in Chapter 5.

Criterion #1: Spatial Systems

A decentralized NMSSS has a positive impact on delivering care depending on the patient room configuration. This criterion identifies the impact of having a decentralized nursing medication and supplies support system design in the caregiver work area in the patient room. Therefore, this criterion defines the relationship between the area that the Nurserver occupies and the patient room (not including toileting).

Criterion #2: Adaptability

According to Hamilton (1999), flexibility is desired to allow for more rapid adjustment of change because this theoretically permits a superior clinical response. This criterion identifies the internal layout “convertible” flexibility, allowing inexpensive conversion to a new use – capable of modification, and the room “adaptable” flexibility to different functions, allowing change in the current use – adjustable to changes (Hamilton, 1999). Therefore, this criterion defines both the reconfiguration of the room to either achieve specific needs or to customize the layout to meet nurses' requirements and the different space functioning choices.

Criterion #3: Patient Safety

This criterion identifies how the NMSSS function in relation to an event of an unscheduled medication. Examples of unscheduled medication are: pain medication, sedatives, and nausea medication. Depending on the patient diagnostic, the caregiver may give as little as no unscheduled medication to a medication every hour - pain medication could be given every hour. Therefore, this criterion defines how long it takes for the caregiver to deliver unscheduled care, considering, on average, a round-trip starting in the patient room.

In addition, this criterion identifies the infection cases that can be related to the number of people that use the NMSSS and can spread contaminated medication and supplies. Therefore, this criterion also defines the potential level of patient contamination related to the nursing medication and supplies support system.

Criterion #4: Security and Theft

Centralized and decentralized NMSSS have a different security behavior and exposure to the patient and the family and to the public. Intentionally or by mistake, the family can pack up everything in the room that they find thinking it is theirs. This criterion identifies the frequency of theft by patient and/or family and by anyone in the corridors. Therefore, this criterion defines both how often the theft occurrence by patient and/or family and from corridor side are.

Criterion #5: Safety in Use

Centralized and decentralized nursing medication and supplies support system have a different technology associated with access to medication and supplies. In addition, the identification system for medication is one strategy to minimize medication errors and maximize patient safety. This criterion identifies levels of technology associated to the medication and/or supplies accessibility and to the medication identification. Therefore, this criterion defines both how the medication and/or supplies accessibility interface and the identification system are.

Criterion #6: Staff Efficiency

Ulrich *et al* (2004) mentioned that walking is the second most time-consuming activity for nurses, which helps increasing nurses' fatigue. Furthermore, based on studies, Ulrich *et al* also mentioned that "time saved walking was translated into more time spent on patient-care activities and interaction with family members".

This criterion was created to identify the nurse and the materials management level of efficiency in a given unit layout. The nurse efficiency is calculated by the amount of time that the caregiver uses to access the medication and deliver it to the patient. Then, the more care per distance the better. The materials management efficiency is calculated by the amount of time used to access the unit's rooms and restock them. Therefore, this criterion defines how much care per walking distance the nurse will deliver and the percentage of time that materials management uses in trips to provide medication and/or supplies to the patient during an 8 hr-shift.

Criterion #7: Patient Satisfaction

Noise is a factor that generates negative effects on patient outcomes and increases patient stress (Ulrich *et al*, 2004). The use of key and drawers to control door cabinet's access in decentralized nursing medication and supplies support system can be disturbing for the patient, especially when accessed at night. In addition, in the hospital environment, cleanliness factor is a crucial issue to provide a healing environment. NMSSS depends on the quality of services provided and residual odors from soiled linen and dietary trays could be an issue.

This criterion identifies the disruption frequency related to noise emission, the room cleanliness and odor quality. Therefore, this criterion defines what would be the potential level of patient disruption related to how often the room is being cleaned.

Criterion #8: Investment Costs

The decentralized nursing medication and supplies support system will be an extra cost because it still requires the centralized system in order to function properly. Then, this criterion identifies the decentralized NMSSS initial cost in relation to the inpatient nursing department gross square feet (DGSF) in which it is inserted in. DGSF represents the "footprint" of the specific department, including the space occupied by internal circulation corridors, walls and partitions, and minor utility columns, in addition to the usable NSF within the department (Hayward, 2006). Therefore, this criterion defines how much the additional initial cost is in relation to the total department cost.

Criterion #9: Operation Costs

The decentralized NMSSS increases the hospital's supply purchase because in addition to having supplies stocked in the Nurservers, a set back up supplies is needed in the Supply Processing and Distribution (SPD) room to replace those used on the units. Then, this criterion identifies the amount of additional supplies and medications required by this storage system.

Nursing Medication and Supplies Support System

The design decision problem requires a good understanding of the effects that the choice can make on the system and its parts, the sub-systems. Choosing between two alternatives for the nursing medication and supplies support system (NMSSS) can be confusing because the result affects a large number of functional aspects of the facility. Thus, an adequate methodology and organization of the criteria in the context of the building system is needed.

"A system is a set of elements to be distinguished from the universe as a function of the purpose of the system" (Augenbroe, 2006). The complexity of a system is given by the number of elements and their interactions. For example, a system can be complex as a building facility or can be simple as a gear. Moreover, the elements of the system are interrelated, and in a given function the system is affect as a whole. (Augenbroe, 2006)

The methodology applied for this study was a system approach to building design based in its functional and technical aspects decomposition (Augenbroe, 2005). This methodology is used during the criteria discovery given the complexities of the building system. The decomposition process is subjective and based in the analyst expertise in such technique and knowledge in the subject matter. Figure 10 introduces an example of the decomposition process for the Case Study presented in this thesis.

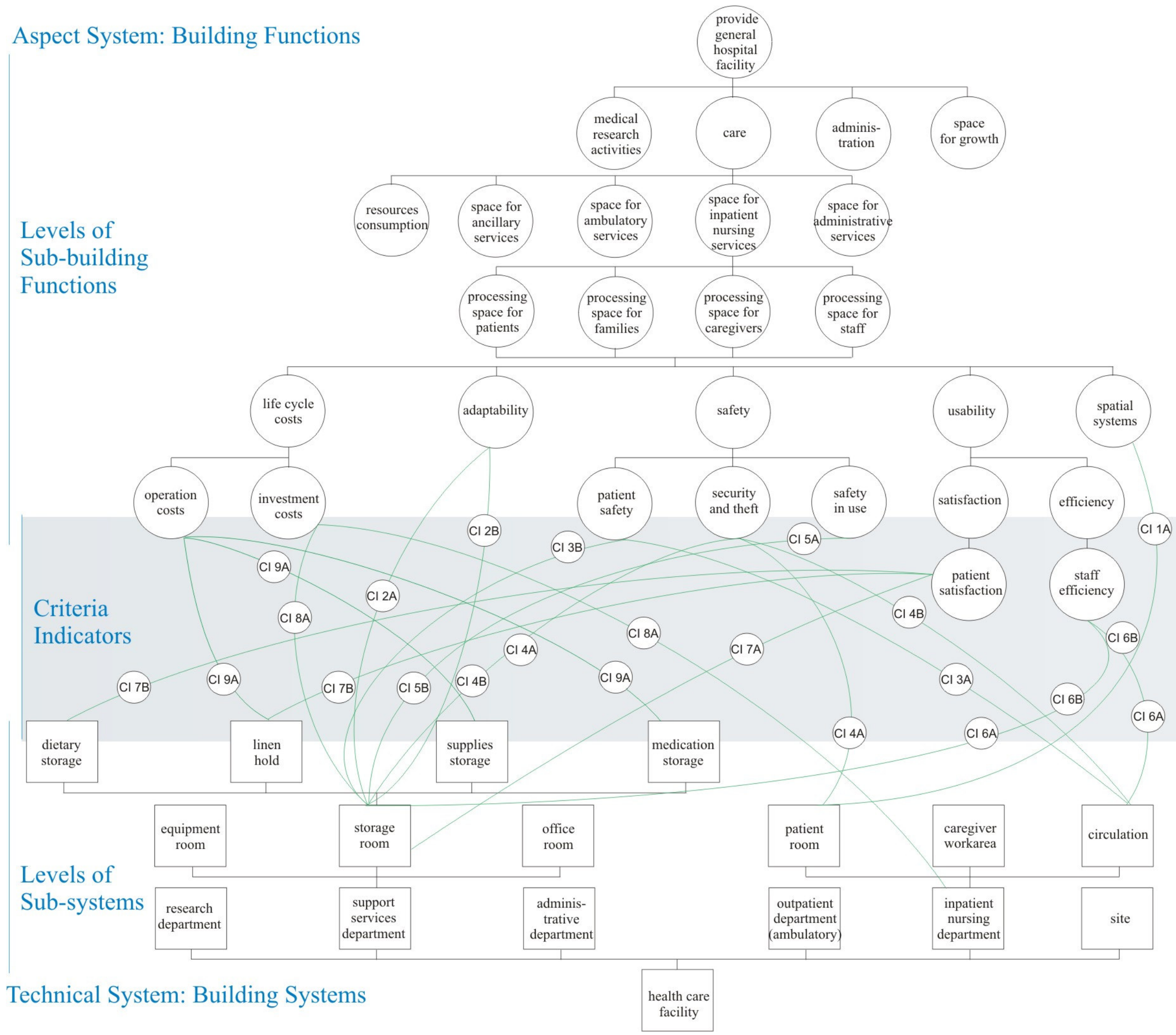


Figure 10: System Theoretic View: the simplified goal coordination (aspect system) and the structural coordination (technical system).
Source: Adapted from Augenbroe, 2006.

The functional aspects are the functions that the system performs, and the technical aspects are the physical building components that will perform these functions. The functional and technical aspects are decomposed into sub-levels of functions and technical sub-systems in order to help the analyst to identify both the relationships between functions and technical elements of the building and which aspects and technical systems are affected by the decision problem. This methodology is important because it examines the formal representation of the system and objectifies and controls all the various functional levels that the alternatives dealt with in the design process by representing the building.

The decomposition of the functional aspects of the NMSSS is shown in a tree diagram (top portion of Figure 10). First, the decision problem was considered in the context of the functions required. The higher level, "provide general hospital facility" was decomposed until one could identify the aspects that will affect the design decision problem, the desired criteria. The result was seven levels of sub-building functions. The criteria identified in the first session of this chapter are presented in the 5th, 6th and 7th levels. This indicates how complex the aspect system can get as it reaches the lower levels. At the same time the sub-systems were decomposed from a higher level until the level of the sub-systems related to the discrete problem alternatives.

At the same time the technical elements were decomposed from a higher level until the level of the technical sub-systems related to the discrete problem alternatives. Then, a connection is established between the functional and technical aspect in order to help in the selection of a "technical solution", or decision problem alternative. The outcome is a constructive diagram for the design problem, bringing together the design program and the design concept.

The connections between the required functions and the technical system represent specific aspects of the technical system. For each connection there are values associated called here “criterion indicator” (CI). The CI is the instrument in which the stakeholders will express their expectations and needs in the functional domain to which the criterion applies. Note that it is possible to establish more than one indicator for the same criterion. For example, there are two CIs for the criteria “adaptability” in relation to the technical sub-system “storage room”. Therefore, the indicators are an important instrument between both design program and the design concept because they help to establish objectives and to organize the decision making. In addition, the designer can efficiently propose design solutions by delimitating the aspects that influence the design problem.

Summary of Chapter 4

A set of nine criteria that play a role in the nursing medication and supplies support system decision problem were identified after meetings with the architectural project manager, and introduced in the first session of this chapter. The criteria are: spatial systems, adaptability, patient safety, security and theft, safety in use, staff efficiency, patient satisfaction, investment costs, and operation costs.

In addition, a system approach methodology is introduced in order to structure the criteria and criteria indicators in the context of the building aspects systems and technical systems. This methodology is based in the building systems decomposition and an example for the NMSSS is presented in the Figure 10.

CHAPTER 5

CRITERIA DEVELOPMENT

This chapter documents the criteria development, the criterion indicators (CIs), through five value levels. The CIs were developed based in the information gathered through the questionnaires, interviews, and diverse sources such as published literature, the Internet, and trade magazines. The values are the instruments used to determine the stakeholders' expectations and needs. The criteria were classified regarding two forms of development: through simple measurements and calculations and through simulation.

Criteria Developed Through Simple Measurements and Calculations

The data used to formulate the following criteria were mainly gathered through questionnaires and interviews with staff from Athens Regional Medical Center, Athens GA, and Hamilton Medical Center, Dalton, GA.

Criterion #1: Spatial Systems

<u>CI 1A: Patient Room Relationship</u>

The main issue is the caregiver work area in the patient room (not including toileting). The value is selected according to the average area of all patient rooms adopted in the unit.

Table 4: CI 1A Values and Description

Values	Description
1	Critical. The patient room has excellent work area. There is a need for the Nurserver - storage closet, and its area will not compromise the delivery of care. The patient room area is greater than or equal to 380sf.
2	Very important. The patient room’s area is above the average and the Nurserver will increase the caregiver efficiency. The patient room area is less than 380sf and greater than or equal to 300sf.
3	Important. The patient room’s area is acceptable and the Nurserver will increase the caregiver efficiency. The patient room area is less than 300sf and greater than or equal to 210sf.
4	Unimportant. The patient room’s area is below average. The Nurserver can be replaced by furniture in the room. The patient room area is less than 210sf and greater than or equal to 130sf.
5	Trivial. There is the need for more area into the patient room. The Nurserver will compete for this area. The patient room area is less than 130sf.

Criterion #2: Adaptability

CI 2A: Space Reorganization

The main issues are time and cost. The reorganization of the room is considered in relation to the room enclosure, shelves, doors, drawers, trays, and locks’ flexibility of re-adaptation. The cost is calculated according to the cost of a registered nurse (RN) work/hour.

Table 5: CI 1A Values and Description

Values	Description
1	The space reorganization is practical: it can be done in minutes or, at most, in an hour. The internal and external room enclosure can be removed. The doors can be replaced. Shelves can be added or removed. There is installation provision for extra drawers, trays and locks. There is space provision for storage with extra shelves and trays.
2	The room can be modified into a different use with relatively small actions (for example, high acuity to low acuity care). The system can have a different use and the reorganization can be done costing less than 3hs work of a RN.
3	For the reorganization of the room will be necessary a small renovation - construction work – requiring less than 5hs work of a RN. This renovation will need little time, less than two days.
4	For the reorganization of the room it will be necessary a renovation - construction work – costing less than 10hs work of a RN. This renovation will need less than three days.
5	For the reorganization of the room will be necessary a renovation - construction work – costing equals to or greater than 10hs work of a RN. This renovation will need three days or more.

CI 2B: Changing Purpose of the Room

The main issues are time, cost, and functions that the room can perform. The cost is calculated according to the cost of a RN work/hour.

Table 6: CI 2B Values and Description

Values	Description
1	The room can be modified into a different use with relatively small actions (no longer than an hour, costing less than 1h work of a RN). The space can function as storage (medical objects -clean and soiled, snacks, patient's personal objects, etc.) and can be an open space for other functions (its enclosure can be relocated in order to allow the free space to be used as an alcove, to receive a vendor machine, or to be added to the patient room. There will be provision for outlets).
2	The room can be modified into a different use and this takes no longer than 2 hours of a day, costing less than 2h work of a RN.
3	The room can be modified into a different use and this takes no longer than 5 hours of a day, costing less than 5h work of a RN.
4	The room can be modified into a different use but restricted to storage, costing less than 10hs work of a RN and taking less than 3 days.
5	Any change in the room costs greater than 10hs work of a RN and taking more than or equal to 3 days long.

Criterion #3: Patient Safety

CI 3A: Nursing Response

The main issues are time and distance. The value is selected according to the average time spent in one round trip from each patient – bed location - in the unit to the source of medication and/or supplies, including the time to unlock, open, find the medication / supplies, and close. The nurses' walking speed is assumed to be uniform and equal to 150 fpm (50 meters / minute), which is a conservative estimate for comfortable human walking speed. It is also the default value used by MedModel (ProModel Corporation, 2006).

Table 7: CI 3A Values and Description

Values	Description
1	Up to 30 seconds.
2	From 31 to 120 seconds (2 minutes).*
3	From 121 to 180 seconds (3 minutes).
4	From 181 to 240 seconds (4 minutes).
5	More than 240 seconds (4 minutes and 1 second).

* Applies mostly to the medication room trip of the Houston Medical Center, Warner Robins GA, Neuro/Ortho unit layout. Values calculated based in Table 20 in the session "Criterion Development through simulation".

CI 3B: Infection Control

The value is selected according to the number of people that uses the system and can sprawl contaminated objects.

Table 8: CI 3B Values and Description

Values	Description
1	Never. There is no related contamination by the storage system.
2	Rarely. There is contamination while restocking the room and it happens no more than once per year. No more than two people have access to the room.
3	Sometimes. There is contamination while restocking the room and it happens twice per year. No more than three people have access to the room.
4	Often. There is contamination while restocking the room and it happens three times per year. No more than five people have access to the room.
5	Always. There is contamination while restocking the room and it happens every month. A least five people have access to the room.

Criterion #4: Security and Theft

CI 4A: Security Theft

The value is selected according to the frequency of theft by patient and/or family.

Table 9: CI 4A Values and Description

Values	Description
1	Never. There are no theft occurrences related by patient and/or family.
2	Almost never. No more than once per year a case of theft is related to patient or family.
3	Rarely. No more than twice per year a case of theft is related to patient or family.
4	Sometimes. No more than four times per year a case of theft is related to patient or family.
5	Often. Theft related to patient or family happens at least once per month.

CI 4B: Theft from Corridor Side

The value is selected according to the level of frequency of theft from corridor side.

Table 10: CI 4B Values and Description

Values	Description
1	Never. There is no theft occurrence from corridor side.
2	Almost never. Cases of theft related to the corridor side occur no more than once per year.
3	Rarely. Cases of theft related to the corridor side occur no more than twice per year.
4	Sometimes. Cases of theft related to the corridor side occur no more than four times per year.
5	Often. Theft from the corridor side happens at least once per month.

Criterion #5: Safety in Use

CI 5A: Information Technology Interface

The value is selected according to the level of technology associated to the medication and/or supplies accessibility.

Table 11: CI 5A Values and Description

Values	Description
1	Finest. The medication and/or supplies accessibility is controlled by the responsible nurse with biometric technology.
2	Excellent. The medication and/or supplies accessibility is controlled by the responsible nurse with a sliding card system.
3	Average. The medication and/or supplies accessibility is controlled by the responsible nurse with a personalized locked combination door.
4	Poor. The medication and/or supplies accessibility is controlled by the responsible nurse with keys.
5	Unsatisfactory. There is no technology associated with the system.

CI 5B: Identification Systems for Medication

The value is selected according to the level of technology associated to the medication identification.

Table 12: CI 5B Values and Description

Values	Description
1	Finest. The identification of medication is controlled by the responsible nurse. Patient, patient's records and medication and/or supplies are checked by the system.
2	Excellent. The identification of medication is controlled by the responsible nurse. Patient records and medication and/or supplies are checked by the system.
3	Average. The identification of medication is controlled by the responsible nurse. Only medication and/or supplies are checked by the system.
4	Poor. The identification of medication is controlled by the responsible nurse with no technology associated.
5	Unsatisfactory. No identification system for medication is required.

Criterion #6: Staff Efficiency

CI 6B: Materials Management Staff Efficiency

Main issues are time, distance, and materials management routine. The value is selected according to the percentage of time the materials management will use in trips to restock medication and/or supplies to the system, including the time to restock. The calculation should consider five days with an eight (8) hours shift. The materials management walking speed is assumed to be uniform and equal to 150 fpm. In addition, the average time (in minutes) to restock and number of trips (frequency per week) for each medication room and Nurserver is assumed to be respectively, 30 and 2.5 (minutes) and 5 and 3 (times per week).

Table 13: CI 6B Values and Description

Values	Description
1	The material management spends up to 1% of the time in trips to provide medication and/or supplies for the patient (1% = 4hs).
2	The material management spends less than 2% and greater than or equal to 1% of the time in trips to provide medication and/or supplies for the patient (2% = 8hs).
3	The material management spends less than 3% and greater than or equal to 2% of the time in trips to provide medication and/or supplies for the patient (3% = 12hs). *
4	The material management spends less than 4% and greater than or equal to 3% of the time in trips to provide medication and/or supplies for the patient (4% = 16hs). **
5	The material management spends greater than or equal to 4% of the time in trips to provide medication and/or supplies for the patient (4% = 16hs).

* Applies mostly to the medication room design option in the Houston Medical Center, Warner Robins GA, Neuro/Ortho unit layout.

** Applies mostly to the Nurservers design option in the Houston Medical Center, Warner Robins GA, Neuro/Ortho unit layout.

Criterion #7: Patient Satisfaction

CI 7A: Patient Disruption

The value is selected according to the disruption frequency related to noise emission.

Table 14: CI 7A Values and Description

Values	Description
1	Never. There are no disruptions or negative effects.
2	Rarely. There is noise while restocking the server and it happens once per month.
3	Sometimes. There is noise while restocking the server and it happens two or three times per week.
4	Often. The restocking process is noisy and causes patient disruption once per day, everyday.
5	Always. Restocking process and access to medications and supplies cause noise that is noticed by the patient every day.

CI 7B: Cleaning and Odor Issues

The value is selected according to the room cleanliness and odor quality.

Table 15: CI 7B Values and Description

Values	Description
1	Always. The room is cleaned everyday, every three hours. The odor quality is good.
2	Often. The room is cleaned everyday, twice per day.
3	Sometimes. The room is cleaned everyday, once per day.
4	Almost never. The room is cleaned every week, two times per week.
5	Never. There is no staff responsible for cleaning the room. Empty meal trays and IV bottles, and dirty linens give off odor that is noticed by the patient. The odor quality is poor.

Criterion #8: Investment Costs

CI 8A: Initial Costs

The value is selected according to the percentage of additional initial cost in relation to the total department cost. Note that the initial cost is only related to the decentralized nursing medication and supplies support system design. The centralized nursing medication and supplies support system design cost is not calculated because it is also included in the decentralized system design.

Table 16: CI 8A Values and Description

Values	Description
1	The cost of the Nurservers is less than 0.5% of the inpatient nursing department gross square feet total cost.
2	The cost of the Nurservers is less than 1.0% and greater than or equal to 0.5% of the inpatient nursing department gross square feet total cost. *
3	The cost of the Nurservers is less than 1.5% and greater than or equal to 1.0% of the inpatient nursing department gross square feet total cost.
4	The cost of the Nurservers is less than 2.0% and greater than or equal to 1.5% of the inpatient nursing department gross square feet total cost.
5	The cost of the Nurservers is greater than or equal to 2.0% of the inpatient nursing department gross square feet total cost.

* Applies mostly to the Nurservers design option in the Houston Medical Center, Warner Robins GA, Neuro/Ortho unit layout.

Criterion #9: Operation Costs

CI 9A: Cost of Additional Supplies

The value is selected according to the percentage of amount of additional supplies that the decentralized nursing medication and supplies support system design requires by the storage system.

Table 17: CI 9A Values and Description

Values	Description
1	Minimum. The system operates with the standard amount of supplies and medications needed.
2	Low. The system operates with an additional of up to 25% in relation to the standard amount of supply and medications needed.
3	Moderate. The system operates with an additional of less than 50% and greater than or equal to 25% in relation to the standard amount of supplies and medications needed.
4	High. The system operates with an additional of less than 75% and greater than or equal to 50% in relation to the standard amount of supplies and medications needed.
5	Maximum. The system operates with an additional greater than 75% in relation to the standard amount of supplies and medications needed.

Criterion Developed Through Simulation

The many complexities and interactions involved in calculating the CI 6A: Nursing Staff Efficiency led the researcher to investigate the use of a mathematical simulation software tool. There are a range of commercially simulation tools for production systems available, such as Arena and ProModel. MedModel, which is a specialized version of ProModel, was chosen for being a tool tailored to the simulation of healthcare systems.

Building Simulation using MedModel

Simulation is the representation of the behavior or process of a real-world system through the use of another system over time. According to Harrell, Ghosh and Bowden (2003), MedModel is a process simulation tool that views the health system arranged by spaces through which items and resources are managed based in healthcare process logic. MedModel is a can be used in the building Pre-Project Phase and Design Phase in order to better understand the implications of the design alternatives. Hence, MedModel is also a decision support tool.

CI 6A: Nursing Staff Efficiency

The Houston Medical Center, Warner Robins GA (Neuro/Ortho unit layout shown in Figure 11), which is still in the design phase, was used to quantify this CI. These CI determinants are both time to access and transport the medication and/or supply and time to deliver it to the patient. The time to access and transport is a function of the distance from the source to the patient. The time to deliver the medication and/or supply to the patient is based mainly on the medication type and the patient's level of acceptance when receiving the medication.

Figure 11: Neuro/Ortho unit layout from Houston Medical Center, Warner Robins GA.
Source: Courtesy from HKS Inc., Atlanta.

According to the Athens Regional Medical Center staff interviews, it takes on average five minutes for an obedient patient to get his / her oral medication, but an additional five to ten minutes for a disobedient patient in the same condition. Also, a patient receiving pain medication intravenously could take up to fifteen minutes to be administered. Therefore, each patient's diagnosis and behavior will result in a specific treatment approach.

There is also a specific amount of trips depending on the patient type and diagnosis. For example, on average, a non-surgical patient with chronic conditions and with a three times per day routine medication requires one or two more medication trips per day given to new orders, such as unscheduled medication or changes in the routine.

For a surgical patient, the average number of trips is seven to eight per 12hr-shift. However, if this patient cannot take medication orally and is feeling pain, he/she would require medication every two hours. Pain medication, sedatives, and nausea medication are examples of unscheduled trips for medication. Depending on the patient, a nurse may give no unscheduled medication to a medication every hour (pain medication for example could be given every hour). Therefore, the real-world system is complicated, informal, heuristic, and has last minutes changes.

Planning the Model

The objective of the model was a comparison study in order to quantify how well does the centralized nursing medication and supplies support system design (design option A) perform compared to the decentralized nursing medication and supplies support system design (design option B). The comparison was based in the Houston Medical Center, Warner Robins GA, Neuro/Ortho unit layout. During 12 hr-shifts, the simulation compared the design options based in two cases: a case in which there are assumptions that negatively affect the efficiency and a case in which there are assumptions that positively affect the efficiency. Therefore, for either design option A or design option B there were two extremes. The real outcome lied somewhere in the intervals of these extremes. The two modeling cases were defined according each patient type and design alternatives (Table 18).

Table 18: Modeling cases breakdown.

Modeling Cases	**Assumptions**
Design Option A No Nurservers Design	negative affect to efficiency positive affect to efficiency
Design Option B With Nurservers Design	negative affect to efficiency positive affect to efficiency

Modeling Assumptions

Several assumptions were made before building the model. The model data was mainly based on questionnaires and interviews with staff from Athens Regional Medical Center, Athens GA, and Hamilton Medical Center, Dalton, GA. From the previous sections one can observe how problem are complex in a healthcare setting. Hence, for the purpose of this study, the modeling environment was simplified given that many factors were "unknown" or "uncertain" at the time that the model was being built.

The first assumption was in relation to patient ratio per nurse. There are eighteen patient rooms for each of the two wings. Four nurses will be assigned for each wing, which results in a ratio of five and four patients per nurse. The second assumption is regarding time to deliver medication and/or supplies and time that is not to deliver medication and/or supplies. Both times are constant to a variable number of trips to each room with a waiting time of N (10, 5), and a fixed number of six trips to the “idle” condition with a waiting time of N (20, 1), respectively.

The third assumption is in relation to trips per patient type. Houston Medical Center Neuro/Ortho unit is a Medical and Surgical unit. Nursing trips behavior to a medical patient is different than that for a surgical patient. Trips to the two types of patients were defined according to the Table 19. Note that the surgical patient requires a similar number of trips to the medication room, even if there is A Nurserver in the patient room. The hypothesis for this occurrence is that the surgical patient needs narcotics and/ or controlled medication which cannot be stocked in the Nurservers for security reasons.

Table 19: Patient types and number trips needed according to each design alternative.

Number of Trips/ Patient Type	**Medical**	**Surgical**
Avg. Number of Trips Needed to the Nurserver	05	01
Avg. Number of Trips Needed to the Medication Room if There is Nurserver in the Nursing Unit	01	07
Avg. Number if Trips Needed to the Medication Room if There is No Nurserver	05	07

The numbers in Table 19 reflect estimates based on information gathered through informal interviews with members of the nursing staff from Athens Regional Medical Center. These numbers are used here to develop the initial assumptions used to test the methodology.

The process of building the model required selection of strategic rooms in order to represent a negative or positive affect to the centralized and decentralized nursing medication and supplies support system. Hence, a simple and naïve route out and back model was built in order to understand the walking behavior between the two wings of the proposed floor layout.

Each of the eight nurses was assigned to a specific set of rooms, specified in the Figure 12. They performed five trips from the medication room, highlighted by the yellow circles, to the patient room, according to the room sequence number. The nurse assigned for the Group 1 performed trips to the medication room A, the nurses assigned for the Groups 2, 3, and 4 performed trips to the medication room B, the nurse assigned for the Group 5 performed trips to the medication room D, and the nurses assigned for the Groups 6, 7, and 8 performed trips to the medication room C.

The “waiting” time in each patient room follows a normal distribution with a mean of 10 minutes and a standard deviation of 5 minutes. The nurses exit the system after a 12 hr shift. The results of 100 replications of this simulation model are presented in Table 20.

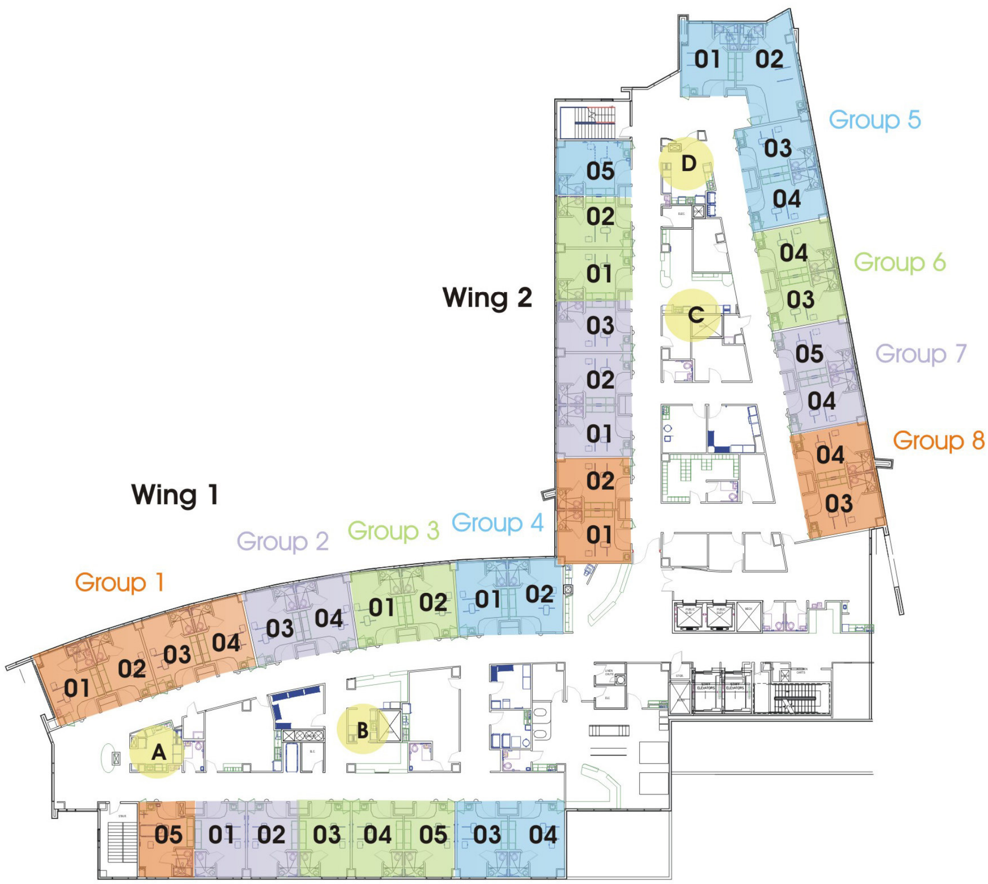


Figure 12: Room distribution per nurse according to room location.

Table 20: Nursing walking time on round trips from medication room to assigned patient room.

Nurse's Group	Number of Patients Assigned	Avg. Time in Move Logic (minutes)
Group 01	05	15.02
Group 02	04	12.89
Group 03	05	15.39
Group 04	04	25.18
Group 05	05	10.41
Group 06	04	9.25
Group 07	05	15.50
Group 08	04	23.79

The results in the Table 20 suggested that the average walking time of the groups 01 through 04 is greater than the average walking time of the groups 05 through 08. Therefore, through this simple model one can conclude that wing 1 has a greater walking time than wing 2. There are several factors that contribute for this difference, such as medication room placement, overall distance of each wing, and differences between patient room sizes.

The rooms' layout, Figure 13, for each scenario was defined based on the results presented in the Table 20. The nurse in the wing 1 is assigned to five patients and the route, based on the patient with greatest need, is represented by the rooms' number. Note that the location of the rooms is not favorable in this wing. The nurse in the wing 2 is assigned to four patients and the route, based on the patient with greatest need, is represented by the rooms' number. Note that the location of the rooms is favorable wing 2.

Figure 13: Room distribution per nurse according to assumptions with negative affect to efficiency (wing 1) and to assumptions with positive affect to efficiency (wing 2).

<u>Building the Model</u>

Problem statements for design option A and for design option B were developed.

Problem Statement 01

The nurses work in an environment with centralized nursing medication and supplies support system (design option A). There are two nurses in the system, one for each wing, and they have the same speed which is equal to 150 fpm. The nurses start the 12 hr-shift at the Med Room to collect the medication in a normal distribution of 0.75 minutes with a standard deviation of 0.25 minutes. Then the nurses go to the Patient Room 01 to deliver care that is normally distributed with a mean of 10 minutes and a standard deviation of 5 minutes. Then the nurses go back to the medication room to collect medication for the next patient, following the room numbering sequence. After going to all patient rooms, the nurses remain idle in the medication room; normally distributed with a mean of 20 minutes and a standard deviation of 1 minute (this is the waiting time before starting a new round trip. The nurses perform six trips to the idle condition). The nurses continue the process through the 12 hr-shift, and after that, they exit wherever they are.

Based on the problem statement, a model flowchart was developed (Figure 14).

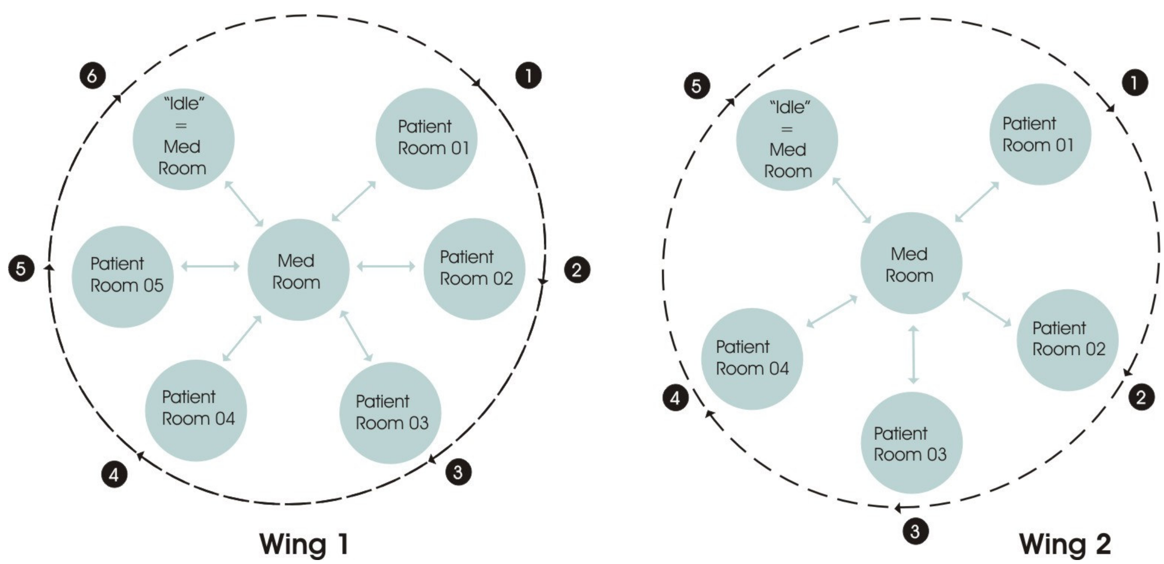


Figure 14: Model flowchart for the scenario with assumptions that negatively affects efficiency (wing 1) and for the scenario with assumptions that positively affects efficiency (wing 2).

Problem Statement 02

The nurses work in an environment with decentralized nursing medication and supplies support system (design option B). There are two nurses in the system, one for each wing, and they have the same speed which is equal to 150 fpm. The nurses start the 12 hr-shift at the Patient Room 01 to deliver care that is normally distributed with a mean of 10 minutes and a standard deviation of 5 minutes. Then the nurses go to the next patient room following the room numbering sequence. After going to all patient rooms, the nurses remain idle in the patient room 01; normally distributed with a mean of 20 minutes and a standard deviation of 1 minute (this is the waiting time before starting a new round trip. The nurses perform six trips to the idle condition). During the entire shift, the wing one's nurse does seven trips from each patient room to the Med Room to pick up narcotics and/ or controlled drugs in a normal distribution with mean equal to 0.75 minutes and a standard deviation of 0.25 minutes and goes back to the patient room. The remaining trips do not include the medication room. The nurses continue the process through the 12 hr-shift, and after that, they exit wherever they are.

Based on the problem statement, a model flowchart, Figure 15, and a model for each design option were developed, Figure 16, and the results are described in Table 21 and Table 22.

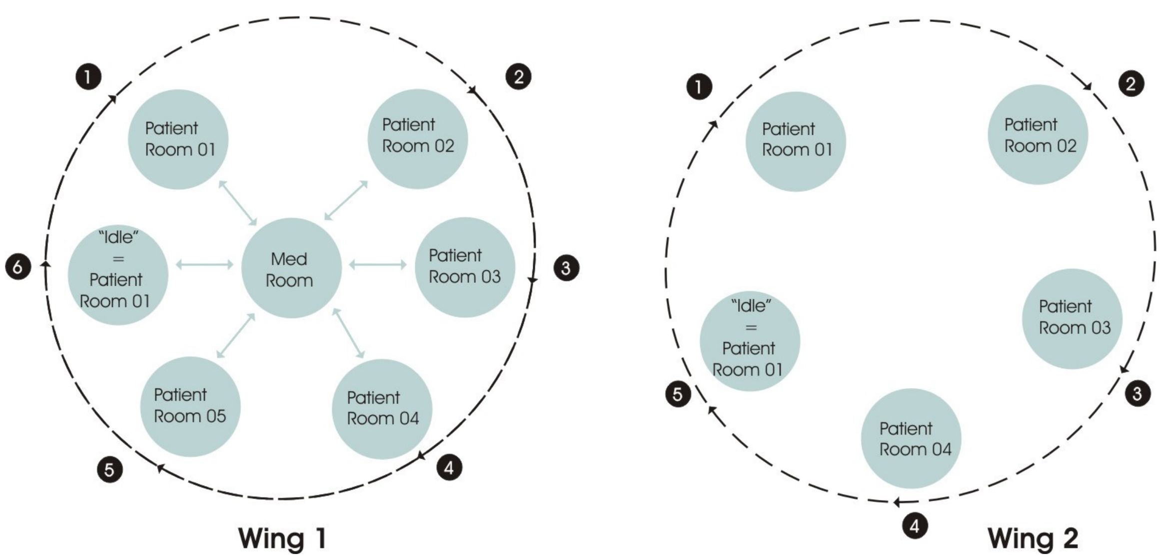


Figure 15: Model flowchart for the scenario with assumptions that negatively affects efficiency (wing 1) and for the scenario with assumptions that positively affects efficiency (wing 2).

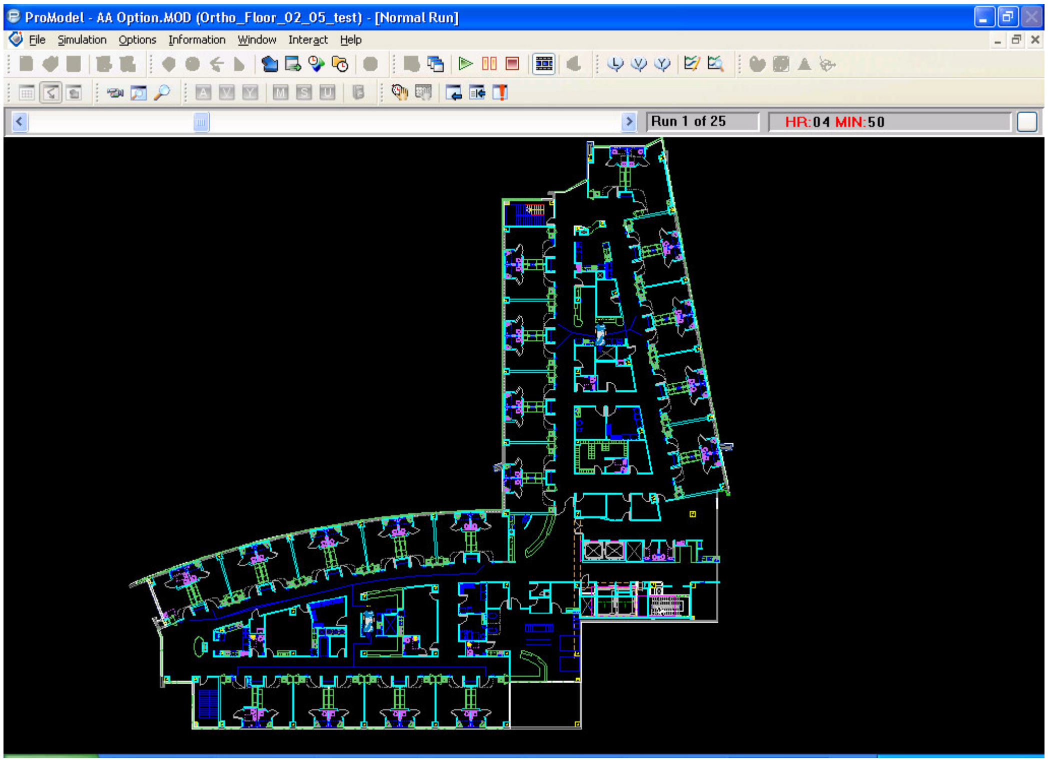


Figure 16: MedModel simulation for design option A with the two nurses in the "idle" condition at the medication room: scenario with assumptions that negatively affects efficiency (wing 1) and scenario with assumptions that positively affects efficiency (wing 2).

Table 21: Results from the simulation for design option A.

Outcome/ Nurse's Location	**Nurse at wing 1**	**Nurse at wing 2**
Sum of Avg. of Care Delivered for each Patient (min)	513.5	551.1
Average Walking Time (min)	55.3	13.8
Walked Distance (feet) per 10 minutes of Care	163.9	37.7

Table 22: Results from the simulation for design option B.

Outcome/ Nurse's Location	**Nurse at wing 1**	**Nurse at wing 2**
Sum of Avg. of Care Delivered for each Patient (min)	527.9	595.0
Average Walking Time (min)	52.8	13.5
Walked Distance (feet) per 10 minutes of Care	151.5	34.1

Table 23: Design option A and B average efficiency.

Design Option	Average Efficiency (feet/10 min)
Design Option A - Centralized nursing medication and supplies support system.	61.3
Design Option B - Decentralized nursing medication and supplies support system	55.9

The walked distance (feet) per 10 minutes of care presented in Table 21 and Table 22 are the extremes for the pessimistic and optimistic values of each design option. The efficiency for a given case lies between the intervals and is dependent on many factors that are "unknown" or "uncertain". Assuming that the outcomes of both options are normally distributed one can assume that the average improvement between options A and B is 5.4 feet per 10 minutes of care (Table 23). The averages in Table 23 are used as the extreme points for the scale of nurse efficiency. Based on these values, and considering the nurse's walking speed constant and equal to 150fpm, the levels of the values of the CI 6A are described in Table 24.

Table 24: CI 6A Values and Description

Values	Description
1	The caregiver walks less than 55 feet per 10 minutes of care.
2	The caregiver walks less than 56 feet or greater than or equal to 55 feet per 10 minutes of care.*
3	The caregiver walks less than 57 feet or greater than or equal to 56 feet per 10 minutes of care.
4	The caregiver walks less than 58 feet or greater than or equal to 57 feet per 10 minutes of care.
5	The caregiver walks greater than or equal to 58 feet per 10 minutes of care. **

* Applies mostly to the Nurservers design option in the Houston Medical Center, Warner Robins GA, Neuro/Ortho unit layout.

** Applies mostly to the medication room design option in the Houston Medical Center, Warner Robins GA, Neuro/Ortho unit layout.

Summary of Chapter 5

This chapter introduced the criteria developed through simple measurements and calculations, and criteria developed through simulation. These criteria were developed through criterion indicators (CIs), which give value to the criteria. The values were developed into scale levels to help to base the decision. The procedure for obtaining the values for each CI utilized the data mentioned in Chapter 4, collected through the use of questionnaires (Appendix A), interviews, published literature, the Internet, and trade magazines.

The simulation software MedModel was used to model scenarios in order to develop the value level scales for the Nursing Staff Efficiency CI. Two modeling case scenarios were created, one for each design option (centralized and decentralized nursing medication and supplies support system - NMSSS), and two assumptions were developed for each case: assumptions that negatively affect efficiency and assumptions that positively affect efficiency. The results of these simulation models were then used to establish the average improvement between the design options, which determined the value scales developed for the Nursing Staff Efficiency CI.

CHAPTER 6

PILOT TESTING WORK SESSION

A pilot test was conducted in the form of a work session on March 2007 at the Houston Medical Center, Warner Robins GA. The participants' primary roles in the healthcare industry were: architect, nurse, and administrator.

Work Session Description

Before the session start the participants were advised about the session agenda. The entire session took 1:15 minutes (Table 25). Initially, the architectural project manager gave a brief introduction to the session and presented the author as the session analyst. The participants were in number of 6. There were two nurses invited to the session that did not participate in any of the previous design decisions and did not know about the subject matter of the work session. Therefore, a brief clarification of the problem was presented for them in the first few minutes of the work session.

Table 25: Approximate Comparison of the Agenda and Real Session Outline.

Planned Agenda		Session Outline	
11:30	Introduction: Brief tools explanation and criteria presentation. Brief introduction to MedModel.	11:40	Introduction.
11:45	Participants will read and sign the consent form (required by Georgia Tech's IRB).	11:50	Brief tools explanation and criteria presentation. Brief introduction to MedModel.
		11:55	Participants read and signed the consent form (required by Georgia Tech's IRB).
11:50	1st methodology: EcoProP. Participants will choose CIs and the value levels of each one.	11:57	1st methodology: EcoProP. Participants chose CIs and the value levels of each one.
12:15	2nd methodology: QFD ProP. Participants will rank the CIs according to their importance.	12:16	2nd methodology: QFD ProP. Participants ranked the CIs according to their importance.
12:25	3rd methodology: Decision Lens. Participants will weight the CIs in pairs according to their importance in relation to the problem and design alternatives.	12:24	3rd methodology: Decision Lens. Participants weighted the CIs in pairs according to their importance in relation to the problem and design alternatives.
12:45	Sensitivity analysis of the suggested result. The question "what if..." will be answered.	12:50	Sensitivity analysis of the suggested result. The question "what if..." was answered.
12:55	Session evaluation	12:52	Session evaluation

After the brief introduction, the analyst presented the tools and explained to the participants the methodologies, criteria, and how the criterion indicators were developed. The analyst mentioned that they would be asked questions through the process based on their need and priorities. Finally, the last methodology outcome would suggest a design alternative. Then, discussion on this result would be developed.

Before starting the methodologies, the participants received a sheet of paper with the scales used in the session, space for notes and list of CIs (Appendix B). This sheet helped them to review the numbers and make notes during the entire session. In addition, it avoided the need for the analyst to constantly repeat instructions during the application of the methodology.

EcoProP

The analyst asked the participants to choose CIs that would play a role when deciding between having centralized or decentralized nursing materials support system. The participants chose first CI 6A – Nursing Staff Efficiency – Staff Efficiency (Figure 17), followed by CI 3A – Nursing Response – Patient Safety, CI 6B – Materials Management Efficiency – Staff Efficiency, and finally, CI 9A – Cost of Additional Supplies – Operation Costs. Then, when the analyst asked for an additional CI and/or an extra criterion/ CI the participants responded that they were satisfied with the four chosen.

Table 26: Criteria, CIs, and value level chosen in chronologic order.

Criteria	Criterion Indicators	Value Level Chosen
Staff Efficiency	CI 6A - Nursing Staff Efficiency	Level 2
Patient Safety	CI 3A - Nursing Response	Level 2
Staff Efficiency	CI 6B - Materials Management Efficiency	Level 4
Operations Costs	CI 9A - Cost of Additional Supplies	Level 2

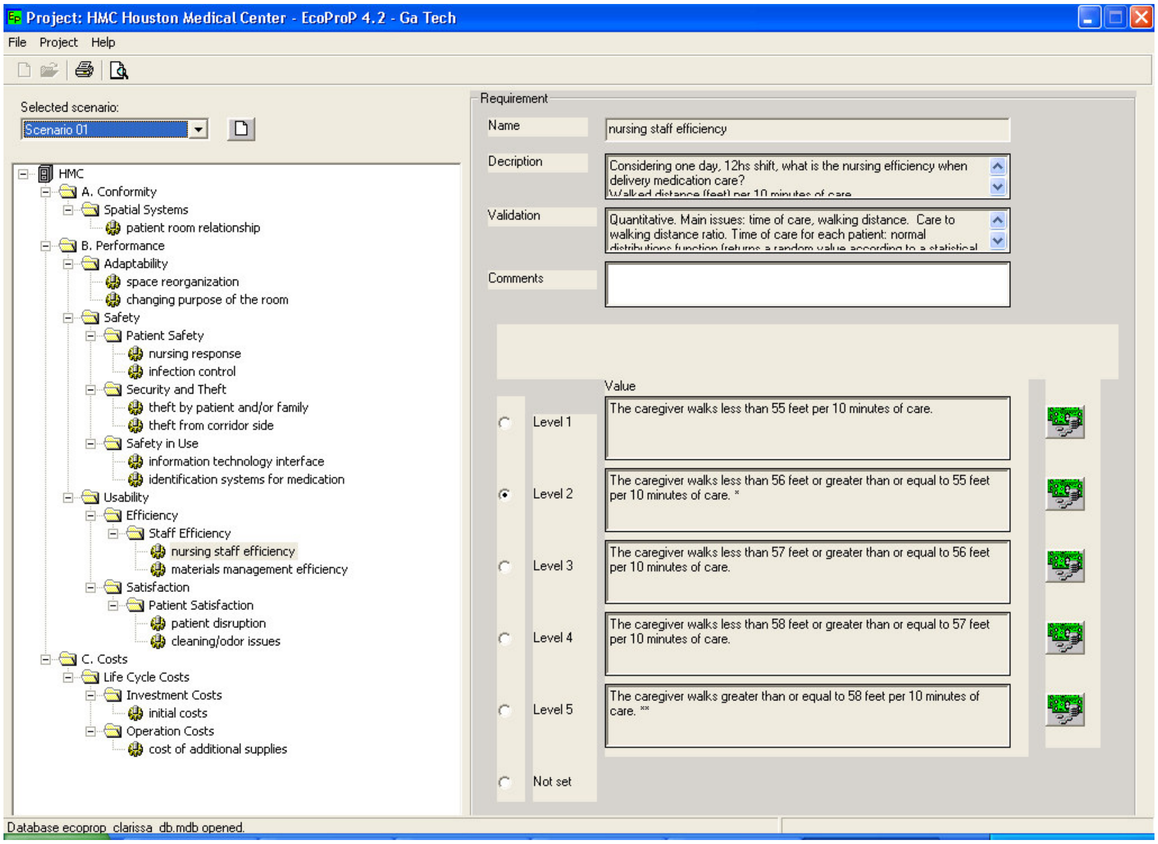
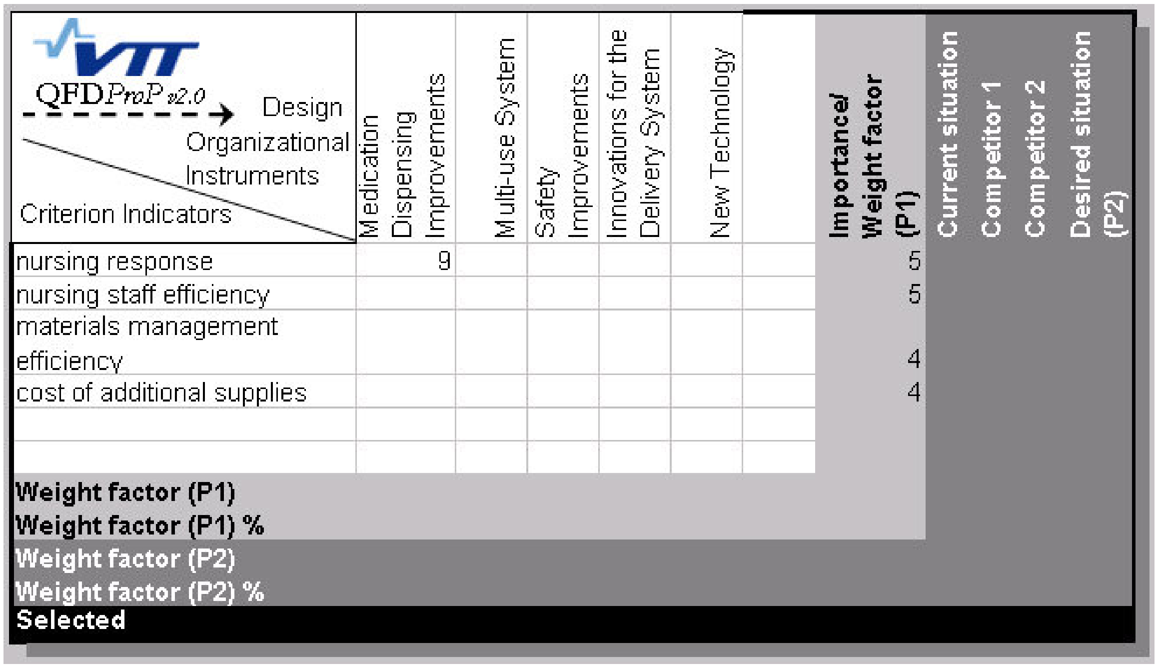


Figure 17: Criterion value level selection for Nursing Staff Efficiency on EcoProP.

QFD ProP

The analyst asked the participants to rank the CIs chosen in the EcoProP software according to their level of importance. The QFD ranking process occurred quickly. This happened because the process of establishing relationships between CI and the organizational instruments was performed only for the relationship between nursing response and medication dispensing improvements (Figure 18). The main reason for that was the limited amount of time available. The participants agreed not to establish relationships between CI and the organizational instruments because they wanted to approach the alternatives' analysis in more detail instead of identifying the organizational instruments of the design.



QFDProP v2.0 Design / Organizational Instruments / Criterion Indicators	Medication Dispensing Improvements	Multi-use System	Safety Improvements	Innovations for the Delivery System	New Technology		Importance/ Weight factor (P1)	Current situation	Competitor 1	Competitor 2	Desired situation (P2)
nursing response	9						5				
nursing staff efficiency							5				
materials management efficiency							4				
cost of additional supplies							4				
Weight factor (P1)											
Weight factor (P1) %											
Weight factor (P2)											
Weight factor (P2) %											
Selected											

Figure 18: Criterion Indicators ranked on QFD ProP.

Decision Lens™ Suite

This methodology was conducted in the end of the work session. The participants started weighting the CI "Nursing Response" high, even when compared to "Nursing Staff Efficiency". The scale levels were between 8 and 9 (very important and extreme important). This generated an inconsistency above 20% in the first comparison result. Then, the participants revised their priorities and a new weight comparison was computed for Nursing Response versus "Nursing Staff Efficiency". The new level of scale was 4 (moderate plus), decreasing the inconsistency level to an acceptable level of 10% (Figure 19). Results of the CIs paired comparison suggested "Nursing Response" approximately two times more important when deciding between alternatives than "Nursing Staff Efficiency" (Figure 19). Note how these two CIs overshadow the "Materials Management Efficiency" and "Cost of Additional Supplies" CIs.

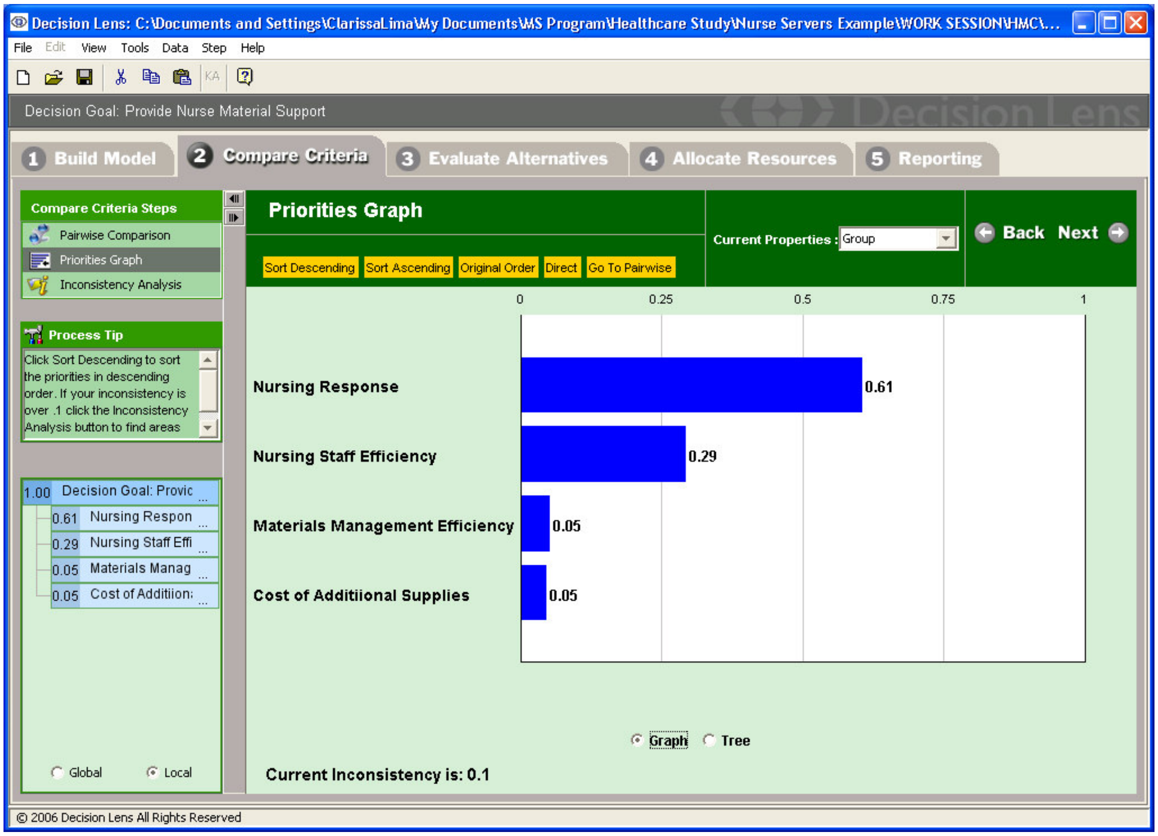


Figure 19: Result of the Paired Comparison of CIs with Respect to the Decision Goal.

The next step was to evaluate the alternatives with respect to a pair of CIs. After all participants' results were computed, the final result of the comparison suggested that "Bed Tower with Nurserver" alternative was four times more desired than not having it (Figure 20). Although the tool suggested an alternative, a brief sensitivity analysis of the results was conducted by adding more value to a different CI - Materials Management Efficiency. This analysis resulted in a different design alternative suggestion. This process clarified the decision environment to the participants (Figure 21). Finally, after the work session, the reports generated by the tools were sent as attachments through electronic mail to the participants (Appendix E).

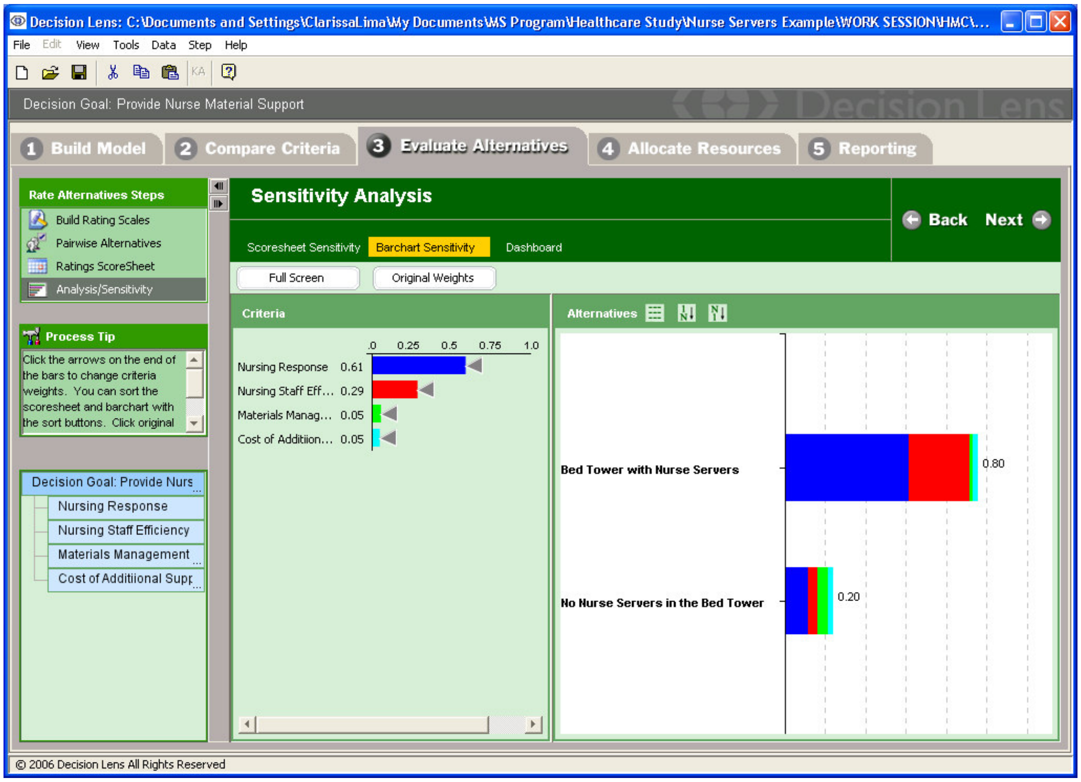


Figure 20: Barchart Sensitivity Analysis Suggesting an Alternative.

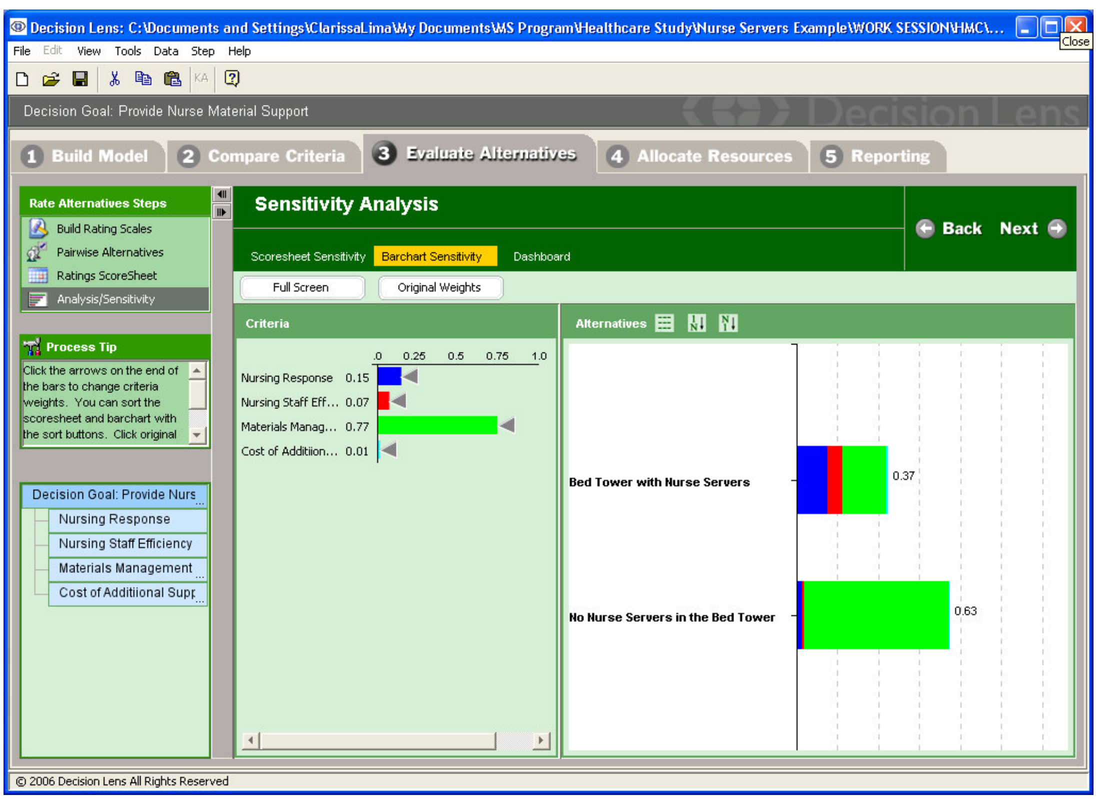


Figure 21: Results Analysis through the Sensitivity Analysis.

Work Session Evaluation

After the tools were applied in a concrete healthcare Pre-Project Phase discrete decision problem, the participants were asked to evaluate the work session and the decision process. A detailed evaluation of the process was performed to determine if the pilot test results corresponded to the expectation that more formal methods could streamline the communication and improve its precision.

Each participant was asked to fill out the evaluation form after the session (Appendix C). The evaluation form was an adaptation of "The Elements of Decision Quality" form proposed by Howard (1988) as a means to measure the quality of the decision "made by any method". The form asked both generic and specific questions regarding subjective evaluation of each tool. The result for each participant is on the Appendix D.

The participants were asked first to evaluate the tools' methodology, followed by the whole analysis process. The analyst aim was both to evaluate whether the tools increased satisfaction of the participants and to identify weakness and strengths in the process. All participants found the problem properly analyzed in EcoProP while presenting the criteria and CIs. In relation to QFD ProP, 66% of the participants evaluated the raking process used in relation to clarification of criteria priority "very important", 17% evaluated "critical", and 17% evaluated "important". Finally, regarding the rating process of Decision Lens when deciding between alternatives, 50% of the participants evaluated it "helpful" and 50% evaluated it "enlightening".

The evaluation of the weakness and strengths of the process was done by asking the participants to share an advantage and a disadvantage of each tool in the decision making process. A total of 19% of the participants' response were inconsistent in relation to the tools and tools' outcomes. A hypothesis of why this happened is that they might not have memorized which tool is related to each method and the tools' sequence. 63% of the answers were consistent and pointed strengths with respect that the tools' increased efficiency, precision and satisfaction of the participants. Only, 13% of the answers pointed out weaknesses in the process regarding the methodologies, which involved 17% of the participants. In addition, 6% of the answers were related to a wrong interpretation of the method. The analysts' hypothesis for these difficulties and misunderstandings is that they were due to the lack of background information before starting the session. However, in general, given the brief session time available for methodology explanation and other unpredicted difficulties, the analyst found the performance of the participants to be very good given their high level of involvement in the process.

The analyst verified the entire process' quality by addressing questions regarding the feasibility of the methodology. The session evaluation showed that 100% of the participants agreed that the methodology clarified aspects of the decision problem and presented a logical sequence of information. Also, all participants found the excellence of the information exposed above the average. Of all participants that evaluated the allocation of effort within the analysis (67%) answered "excellent", "very effective", and "very easy". When asked whether they could apply the methodology in the future, 83% of the participants said "yes", and 17% said "maybe".

Finally, the analyst wanted to judge the whole analysis process in relation to the decision quality. In order to address this issue, the analyst evaluated if the process was well exposed and communicated enough to establish a commitment to action by the participant. When they were questioned about the commitment to action, all respondents (83%) answered that they were committed.

Summary of Chapter 6

This chapter presented the results of the work session which applied the methodologies introduced in the Chapter 2. The six participants agreed in selecting four CIs in EcoProP, then they ranked them in QFD ProP and finally, they weighed the CIs and alternatives in Decision Lens. After the alternative suggestions, a sensitivity analysis of the result was conducted. The participants followed the logic of the process and were satisfied with the first suggested result. They also were surprised with the CIs' weight results, which pointed an unexpected CI as the most important one for the design decision. Overall, the results of the evaluation forms were positive. This suggests that the methodology applied clarified the main aspects of the decision process and improved the communication between the participants.

CHAPTER 7

CONCLUSION

Research Findings

This research addressed the difficulties involved in attaining efficient communication among stakeholders during the Pre-Project Phase. The Pre-Project Phase of building construction manages the communication between client organization, user groups and designers. The main contribution of this thesis was to demonstrate that the use of decision support methodologies improved satisfaction of the parties involved in the decision process. The methodologies clarified for the participants the main aspects and criteria that play a role in their decision. Also, the methodologies rationalized, gave structure, and documented the process, making it possible for the Decision Maker to revisit the decision problem in order to analyze the decision in the future. In addition, these documents will also be useful to the stakeholders as a tracking instrument of the decision outcome during and after the construction phase.

The proposed study evaluated the effectiveness of these tools in the specific case of Pre-Project Phase of a healthcare facility. The Work Session Evaluation part of this thesis, Chapter 6, confirmed the hypothesis of this study regarding the feasibility of the adoption of the proposed methods. Based on the information provided by the participants, it was evaluated that the tools increased efficiency, precision and satisfaction. Therefore, the main contributions of this study are: advancing knowledge and understanding of planning for healthcare facilities in general and investigating the introduction of rational methods to improve communication between stakeholders.

The introduction of rational methods benefited the communication between the participants by exposing a structured and logical decision problem, presenting the main criteria and CIs that play a role in the decision process, quantifying the value levels of the selected CIs and rationalizing the participants' priorities. The participants faced the decision problem analysis objectively and, by the end of the session, comments such as "I am surprised because I found out that an unexpected CI turned out to be the main indicator for my decision" were raised. Thus, a better understanding of the decision problem was achieved. The participants of different backgrounds were able to discuss objectively the problem according to their specific needs. In addition, the participants had an incentive to communicate towards the decision outcome and finally agreed and approved the final suggested design solution.

Directions for Future Work

Although the evaluation of the methods and tools here presented confirmed the hypothesis of the study, the findings justify future research on the following topics.

Extending the Scope of Work

Further study is suggested on the application of the methods in Pre-Project Phase of different facility types. In addition, the application of the methods could be extended to the other phases of facility design, construction, and delivery. Therefore, other facility types/ phases could benefit from the methodology proposed for discrete decision problems.

Involving Stakeholders in the Entire Process

Because of time constraints associated with this study, the data used for the pilot test case study was not gathered from the participants of the work session. This resulted in criteria, CIs, and organizational instruments development that were not efficiently targeted to the needs of the particular participants' decision problem. As a consequence, an extra effort was conducted in order to predict the maximum number of relevant criteria and CIs that could play a role during the decision making. Therefore, future research should capture the "real" information of the participants. This will avoid misunderstanding of the methods during the session and will allow more engagement and freedom to the participants.

Investigating a Decision Problem with Infinite Number of Alternatives

This research addresses the application of a triage of methods for a discrete decision problem with a limited number of design alternatives. However, some design problems either are open to identify a better design alternative solution or they have an infinite number of design solutions. These are two distinct directions for an analysis of the decision and are both common situations in the AEC industry. Therefore, directions for future research include studies involving an appropriate methodology to approach these two distinct directions of decision making.

Investigating the Use of Additional Tools and Analysis Methods

Uncertainties and risks can arise when deciding between alternatives because one can not predict what could be the consequences of alternatives in the future. There is a different probability of success and consensus for each alternative given the information available during the decision problem analysis. Therefore, one can evaluate and select an alternative based on both high level of satisfaction and lower risk. Directions for future work should consider an appropriate method to investigate these issues. In addition, one should evaluate in which scenarios this methodology would be more successful.

Discussion and Further Outlook

This session addresses the main contributions and clarification of the methodologies applied in the Nurserver Case Study.

The Decision Process versus the Decision Outcome

It is important to understand that the methodologies presented do not guarantee that the best alternative will be suggested by the tools nor that it will be selected by the Decision Maker. The decision analysis requires that one first distinguishes between its process and outcome. A good decision does not guarantee positive outcomes. A positive outcome is a future system state that is preferred to other alternatives, and a good decision is a structured action consistent with the information available, preferences of stakeholders, and evaluated alternatives. Hence, one should separate consequence (outcome) from action (decision) in order to understand better the decision process and enhance the decision quality (Clemen, 1996 and Howard, 1988). The reason for that is because the decision analysis does not solve the problem – it formally processes participants' subjective judgments in order to produce insight and assist the Decision Maker to make a better decision when evaluating the alternatives (Keeney, 1982).

The Decision Analyst

Given the fact that the approach proposed in this study suggests the application of the methods in order to objectify the decision making process, it created the need for a decision analyst to manage it. Such decision analyst should be someone impartial in the process, who translates the voice of the costumer into criteria, develops the CIs, clarifies and conducts the decision process, and finally, analyzes the decision outcome. In addition, the decision analyst should be a knowledgeable consultant in the domain of the AEC industry relevant to the problem in question.

Process Creativity and Innovation

Even though the methodologies here presented were identified based on a literature review, one should note that each process is a project that will be addressed to a particular group of stakeholders in a given decision problem scenario. This thesis proposes the introduction of decision support and analysis methodologies in the daily decision problems of facilities' Pre-Project Phase in order to improve satisfaction and precision.

Methodologies Application

The methodologies presented in this study can be employed in decision problems that do not have a clear solution, which are typically complex and involve stakeholders with different backgrounds, priorities and expectations. In such cases, the methodologies will rationalize the problem by introducing and formally processing the subjective judgment of the stakeholders during the alternatives' evaluation. Examples of healthcare decision problems that can benefit from the application of these methodologies include selecting patient room types, nursing station types, and patient life support systems.

APPENDIX A

QUESTIONNAIRE

1. DEMOGRAPHICS

What is your primary role in the healthcare industry?

2. GENERAL QUESTIONS ABOUT NURSERVERS AND MEDICATION ROOMS

(Please consider Accudose and PYXIS servers as medication room)

What is the medication schedule? Please consider an approximate percentage of patient that take one, two, three and four-time medication on your department.

How many Nurservers does the hospital currently have?

Please rate your understanding of accessibility for both, medication rooms and Nurservers:

	excellent	**good**	**fair**	**poor**	**very poor**	**not sure**
Accessibility to the supplies from the medication rooms						
Accessibility to the supplies from the Nurservers						
Accessibility to the patient from the medication rooms						
Accessibility to the patient from the Nurservers						

How does the Nurserver in each patient room function? Please make a circle in one of the following options:
excellent good fair poor very poor not sure N/A

Why?

Which of the following functions are associated with the Nurserver that you work with? Please choose how many it applies.
Linen
Medications
Supplies
The patient's chart

Dietary
Dirty linen
Empty meal trays
Empty IV bottles
Other
If you selected other, please specify.

Is there an additional function for the Nurserver? Please describe.

How often is the Nurserver actually used (what are the assignments from nurse to patients)? Please give an approximate number per nurse, per day, per shift.

How often does the medication room have to be restocked? Please give an approximate number of hours per week.

How often does the Nurserver have to be restocked? Please give an approximate number of hours per week.

Does the nurse have to travel to the medication room (or utility room) even if she has a Nurserver? Please inform an approximate number per nurse, per patient, per shift.

Does the patient receive the medication only during the schedule time, or unscheduled medication could happen? If yes, how often? Please inform an approximate number per nurse, per patient, per shift.

3. QUESTIONS ABOUT STAFF EFFICIENCY

Please state the approximate values in minutes for the medication room and Nurserver:

	minutes
On average, how long does it take you to get to a Nurserver from the nurse station?	
On average, how long does it take you to get to a Nurserver from the patient room?	
On average, how long does it take you to access to supplies on the Nurserver (please consider approximately the time to unlock, open, find the supply, and close the Nurserver)?	
On average, how long does it take you to get to the clean supply room from the patient room?	

In your work setting, who stocks the Nurservers?

In your work setting, who stocks the medication room?

How many people are needed to stock the Nurserver each week?

How many people are needed to stock the medication room each week?

How long does it take to stock the medication room?

How long does it take to stock the Nurservers?

4. QUESTIONS ABOUT PATIENT SAFETY

Please rate:

	very weak	weak	not sure	strong	very strong	N/A
The level of temperature in the medication room						
The level of temperature in the Nurserver						
Infection control in the medication room						
Infection control in the Nurserver						

Do you believe that the incidence of error in the Nurserver would be smaller than the incidence of error in the medication room relation to right patient, right drug, right dose, and right route?

Why? Please explain.

5. QUESTIONS ABOUT PATIENT SATISFACTION ON THE NURSERVERS AND MEDICATION ROOMS

What kind of disruption patients may have regarding medication room?

Are Nurservers disruptive? If yes, how?

Are dietary trays placed in the server? If yes, how often are dietary trays changed per day?

Please rate:

	excellent	good	fair	poor	very poor	not sure
Medication room cleanliness						
Nurserver cleanliness						
Medication room odor quality						
Nurserver odor quality						
The efficiency of removable dietary trays in the Nurservers?						

Please share any additional insights you have about the cleaning aspect of the Nurservers and/or medication rooms. This will be of great help to the designer.

6. QUESTIONS ABOUT SECURITY THEFT IN THE NURSERVERS AND

MEDICATION ROOMS

Please rate:

	very weak	weak	not sure	strong	very strong	N/A
The security level in the medication room						
The security level in the Nurserver						
Considering the Nurservers, the potential theft from corridor side is						
Considering the Nurservers, the potential theft by patient/family is						

How do you evaluate the security of the medication room that you work (worked) with? Please describe how the security system is.

How do you evaluate the security of the Nurserver that you work (worked) with? Please describe how the security system is.

Please share any additional insights you have about security of Nurservers and/or medication rooms. This will be of great help to the designer.

7. QUESTIONS ABOUT MANAGEMENT AND NURSERVERS AND

MEDICATION ROOM COSTS

Please inform the approximate values for the Nurservers and medication room:

	medication rooms	**Nurserver**
What percentage of the bed tower construction cost is needed for construction?		
How much does it cost per year to maintain functioning, considering cleaning and personnel aspects?		
What is the percentage of the supply wasted per year?		
How much does the wasted supply cost per year?		

What is the life time of the Nurservers? Please provide an approximate value.

Question for Pharmacy. Please inform the approximate values for the medication room and Nurserver:

	medication rooms	**Nurserver**
What is the needed temperature range?		
What is the average number of medication errors per year?		
What is the number of infection cases per year		

8. QUESTIONS THAT WILL NEED CAREGIVERS' TRACKING

How many trips do you make to the Nurserver per day and how long do these trips take? Please indicate the approx. number.

How many trips do you make to the medication room and supply room per day and how long do these trips take? Please indicate the approx. number for each room.

9. ADDENDUM

How many patient rooms do you have in your department?

On average, how many trips do you make to the clean and soiled linen rooms per patient per shift?

In your work setting, who stocks the clean and soiled linen rooms?

In your work setting, who provides or removes the patient's linens?

Does the nurse have to travel to the clean and soiled linen rooms even if she has a Nurserver? Please inform an approximate number per nurse, per patient, per shift.

On average, how long it takes to provide or remove the patient's linen?

Based in which rules the nurse visits the patients? (e.g. high acuity to low acuity level of care, room location, etc.) Please describe the nurse routine to visiting the patients.

On average, how long does it take to provide medication to the patient?

On average, what is the maximum number of visits per patient to provide medication and/or supplies per shift?

If you responded that Nurservers are disruptive, how often the disruption happens per week?

How often are the medication room, the clean linen room and the soiled linen room cleaned per day?

How often does theft occur from the corridor, considering the Nurservers?

How often does theft occur from patient and/or family, considering the Nurservers?

Regarding cost of additional supplies, does the Nurserver require an additional amount of supplies and medications per month? How much is this?

APPENDIX B

BASIC INFORMATION SHEET

List of Criterion Indicators

Patient Room Relationship
Space Reorganization
Changing Purpose of the Room
Nursing Response
Infection Control
Theft by Patient and/or Family
Theft from Corridor Side
Information Technology Interface
Identification Systems for Medication
Nursing Staff Efficiency
Materials Management Efficiency
Patient Disruption
Cleaning/Odor Issues
Initial Costs
Cost of Additional Supplies

Notes

QFD ProP Scales

1 Ranking Criteria: "Importance/ Weight Factor"

Scale	*Explanation*
1	not at all important
2	of minor importance
3	of moderate importance
4	very important
5	of highest importance

2 Ranking Organizational Instruments: Relationships

Scale	*Explanation*
1	weak relationship
3	medium relationship
9	strong relationship

*no relationship, no number

Decision Lens Scale of Comparisson

3 Weighting Criteria

Scale	*Verbal Statement*	*Explanation*
1	equal importance	Two activities contribute equally to the objective
2	weak	
3	moderate importance	Experience and judgment slightly favor one activity over another
4	moderate plus	
5	strong importance	Experience and judgment strongly favor one activity over another
6	strong plus	
7	very strong or demonstrated importance	An activity is favored very strongly over another; its dominance demonstrated in practice
8	very, very strong	
9	extreme important	The evidence favoring one activity over another is of the highest possible order of affirmation

APPENDIX C

EVALUATION FORM

Houston Medical Center Work Session, Warner Robins, GA, March 2007

EVALUATION FORM

Please circle the desired answer when appropriate.

What is your primary role in the healthcare industry? ___________________________________

Criteria Management

Was the problem properly analyzed in EcoProP while presenting the criteria?				
Yes	Maybe	No	Not Sure	

Please share an advantage and a disadvantage of EcoProP in the decision making process.
Advantage: Disadvantage:

Rationalization of System Functions

How do you evaluate the raking process used in QFD ProP in relation to clarification of criterion indicators priority?				
Critical	Very Important	Important	Unimportant	Trivial

Please share an advantage and a disadvantage of QFD ProP in the decision making process.
Advantage: Disadvantage:

Multi Criteria Decision Analysis

How do you evaluate the rating process of Decision Lens when deciding between alternatives?				
Slow	Confusing	Enlightening	Helpful	Not Sure

Please share an advantage and a disadvantage of Decision Lens in the decision making process.
Advantage: Disadvantage:

Feasibility of the Methodology – The whole Analysis Process

How do you evaluate the excellence of the information exposed?				
Above Average	Average	Bellow Average	Unsatisfactory	Not Sure

How do you evaluate the allocation of effort within the analysis?

Do you agree that the methodology clarified aspects of the decision problem?				
Yes	Maybe	No	Not Sure	

Do you agree that the methodology presented a logical sequence of information?				
Yes	Maybe	No	Not Sure	

What is the level of your commitment to action?

Would you apply this methodology in the decision making process in the future?				
Yes	Maybe	No	Not Sure	

THANK YOU for participating in this study

APPENDIX D

EVALUATION FORM RESULTS

Houston Medical Center Work Session, Warner Robins, GA, March 2007

What is your primary role in the healthcare industry?	
Subject 01	Clinical Director
Subject 02	Administrator
Subject 03	CNE
Subject 04	Architect
Subject 05	Director, Clinical Practice
Subject 06	Clinical Director

CRITERIA MANAGEMENT

Was the problem properly analyzed in EcoProP while presenting the criteria?	
Subject 01	yes
Subject 02	yes
Subject 03	yes
Subject 04	yes
Subject 05	yes
Subject 06	yes

Please share an advantage and a disadvantage of EcoProP in the decision making process.	
	Advantage:
Subject 01	organizes weights on importance of various aspects
Subject 02	discussion around alternatives
Subject 04	helps gets thoughts on the table
Subject 05	clear graphs that analyze the response
Subject 06	shows +/- no decision making
	Disadvantage:
Subject 01	understanding the questions

RATIONALIZATION OF SYSTEM FUNCTIONS

How do you evaluate the raking process used in QFD ProP in relation to clarification of criterion indicators priority?	
Subject 01	very important
Subject 02	very important
Subject 03	important
Subject 04	critical
Subject 05	very important
Subject 06	very important

Please share an advantage and a disadvantage of QFD ProP in the decision making process.	
	Advantage:
Subject 01	process more rational
Subject 02	interactions/ weighting alternatives
Subject 04	helps prototype
Subject 06	good comparisons with charts
	Disadvantage:
Subject 02	fixed states

MULTI CRITERIA DECISION ANALYSIS

How do you evaluate the rating process of Decision Lens when deciding between alternatives?	
Subject 01	helpful
Subject 02	enlightening
Subject 03	helpful
Subject 04	enlightening
Subject 05	helpful
Subject 06	enlightening

Please share an advantage and a disadvantage of Decision Lens in the decision making process.	
	Advantage:
Subject 02	points out conflicts
Subject 04	gives visual and quantitative look at decisions
Subject 05	clear understanding of the end result
Subject 06	helpful with decision priority
	Disadvantage:
Subject 01	a bit difficult to start but caught on

FEASIBILITY OF THE METHODOLOGY: THE WHOLE ANALYSIS PROCESS

	How do you evaluate the excellence of the information exposed?
Subject 01	above average
Subject 02	above average
Subject 03	above average
Subject 04	above average
Subject 05	above average
Subject 06	above average

	How do you evaluate the allocation of effort within the analysis?
Subject 02	Excellent. Good tool and use of time
Subject 04	very effective
Subject 05	very easy
Subject 06	excellent

Do you agree that the methodology clarified aspects of the decision problem?	
Subject 01	yes
Subject 02	yes
Subject 03	yes
Subject 04	yes
Subject 05	yes
Subject 06	yes

Do you agree that the methodology presented a logical sequence of information?	
Subject 01	yes
Subject 02	yes
Subject 03	yes
Subject 04	yes
Subject 05	yes
Subject 06	yes

What is the level of your commitment to action?	
Subject 02	committed
Subject 03	Want nurse server stocked by materials management on daily basis.
Subject 04	committed
Subject 05	high
Subject 06	good

Would you apply this methodology in the decision making process in the future?	
Subject 01	yes
Subject 02	yes
Subject 03	yes
Subject 04	yes
Subject 05	maybe
Subject 06	yes

APPENDIX E

REPORTS

ECOPROP REPORT

EcoProP report: All requirements

Project: HMC Houston Medical Center

A. Conformity

Spatial Systems

B. Performance

Adaptability

Safety

Patient Safety

Nursing response

Description: How long does it take for the caregiver to deliver unpredicted care? This requirement considers, on average, a round trip starting in the patient room, including the time to find the medication/supply.

Level 2: From 31 to 120 seconds (2 minutes).*

Validation: Main issues: time in seconds, distance. * Applies mostly to the medication room trip or the Houston Medical Center Neuro/Ortho unit layout.

Security and Theft

Safety in Use

Usability

Efficiency

Staff Efficiency

Nursing staff efficiency

Description: Considering one day, 12hs shift, what is the nursing efficiency when delivery medication care? Walked distance (feet) per 10 minutes of care.

Level 2: The caregiver walks less than 56 feet or greater than or equal to 55 feet per 10 minutes of care. *

Validation: Main issues: time of care, walking distance. Care to walked distance ratio. Time of care for each patient: normal distributions function (returns a random value according to a statistical distribution) of 15 minutes with a standard deviation of 2 minutes. Nurses´ walking speed is 150fpm. *Applies mostly to the Nurserver design option in the Houston Medical Center Neuro/Ortho unit layout. **Applies mostly to the medication room design option in the Houston Medical Center Neuro/Ortho unit layout.

Materials management efficiency

Description: Considering 5 days and an 8hs shift, what percentage of time the materials management will use in trips to provide medication and/or supplies to the patient?

Level 4: The material management spends less than 4% and greater than or equal to 3% of the time in trips to provide medication and/or supplies for the patient (4% = 16hs). **

Validation: Main issues: time, distance, materials management routine. *Applies mostly to the medication room design option in the Houston Medical Center Neuro/Ortho unit layout. **Applies mostly to the Nurserver design option in the Houston Medical Center Neuro/Ortho unit layout.

Satisfaction

Patient Satisfaction

C. Costs

Life Cycle Costs

Investment Costs

Operation Costs

Cost of additional supplies

Description: Percentage of amount of additional supplies and medications required by the Nurserver system.

Level 2: Low. The system operates with an additional of up to 25% in relation to the standard amount of supply and medications needed.

Validation: Main issues: percentage of amount of additional supplies and medication stored.

DECISION LENS REPORT

1. Decision Lens Reporting

1.1. Criteria Tree-View

Decision Goal: Provide Nurse Material Support
Nursing Response
Nursing Staff Efficiency
Materials Management Efficiency
Cost of Additional Supplies

1.2. Alternatives Report

- Bed Tower with Nurse Servers
- No Nurse Servers in the Bed Tower

1.3. Participants Report

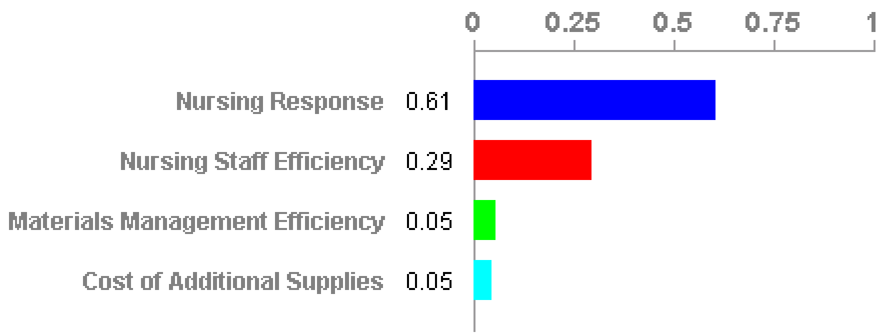
- Participant 1
- Participant 2
- Participant 3
- Participant 4
- Participant 5
- Participant 6

1.4. Weighted Tree-View

Decision Goal: Provide Nurse Material Support	
0.607	Nursing Response
0.293	Nursing Staff Efficiency
0.054	Materials Management Efficiency
0.046	Cost of Additional Supplies

1.5. Priorities Graph

1.5.1. Decision Goal: Provide Nurse Material Support



1.6. Pairwise Comparison

User	Comparison	Score
Participant 6	Nursing Response > Nursing Staff Efficiency	4
Participant 5	Nursing Response > Nursing Staff Efficiency	4
Participant 4	Nursing Response > Nursing Staff Efficiency	4
Participant 3	Nursing Response > Nursing Staff Efficiency	4
Participant 2	Nursing Response > Nursing Staff Efficiency	4
Participant 1	Nursing Response > Nursing Staff Efficiency	4
Combined:	Nursing Response > Nursing Staff Efficiency	4

User	Comparison	Score
Participant 6	Nursing Staff Efficiency > Materials Management Efficiency	9
Participant 5	Nursing Staff Efficiency > Materials Management Efficiency	9
Participant 1	Nursing Staff Efficiency > Materials Management Efficiency	9
Participant 4	Nursing Staff Efficiency > Materials Management Efficiency	8
Participant 3	Nursing Staff Efficiency > Materials Management Efficiency	8
Participant 2	Nursing Staff Efficiency > Materials Management Efficiency	8
Combined:	Nursing Staff Efficiency > Materials Management Efficiency	8.485

User	Comparison	Score
Participant 3	Materials Management Efficiency > Cost of Additional Supplies	7
Participant 1	Materials Management Efficiency > Cost of Additional Supplies	6
Participant 5	Materials Management Efficiency > Cost of Additional Supplies	5
Participant 6	Materials Management Efficiency = Cost of Additional Supplies	1
Participant 2	Cost of Additional Supplies > Materials Management Efficiency	4
Participant 4	Cost of Additional Supplies > Materials Management Efficiency	6
Combined:	Materials Management Efficiency > Cost of Additional Supplies	1.435

User	Comparison	Score
Participant 6	Nursing Response > Materials Management Efficiency	9
Participant 2	Nursing Response > Materials Management Efficiency	9
Participant 4	Nursing Response > Materials Management Efficiency	8
Participant 3	Nursing Response > Materials Management Efficiency	8
Participant 1	Nursing Response > Materials Management Efficiency	8
Participant 5	Nursing Response > Materials Management Efficiency	7
Combined:	Nursing Response > Materials Management Efficiency	8.137

User	Comparison	Score
Participant 1	Nursing Staff Efficiency > Cost of Additional Supplies	9
Participant 3	Nursing Staff Efficiency > Cost of Additional Supplies	8

Participant 2	Nursing Staff Efficiency > Cost of Additional Supplies	8
Participant 6	Nursing Staff Efficiency > Cost of Additional Supplies	7
Participant 5	Nursing Staff Efficiency > Cost of Additional Supplies	7
Participant 4	Nursing Staff Efficiency > Cost of Additional Supplies	7
Combined:	Nursing Staff Efficiency > Cost of Additional Supplies	7.632

User	Comparison	Score
Participant 6	Nursing Response > Cost of Additional Supplies	9
Participant 5	Nursing Response > Cost of Additional Supplies	9
Participant 4	Nursing Response > Cost of Additional Supplies	8
Participant 3	Nursing Response > Cost of Additional Supplies	8
Participant 2	Nursing Response > Cost of Additional Supplies	8
Participant 1	Nursing Response > Cost of Additional Supplies	7
Combined:	Nursing Response > Cost of Additional Supplies	8.137

1.7. Ratings Scale Definitions

1.8. Ratings Scoresheet

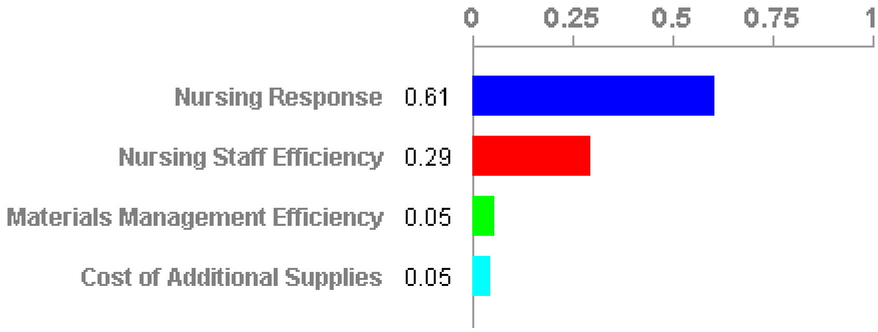
1.9.

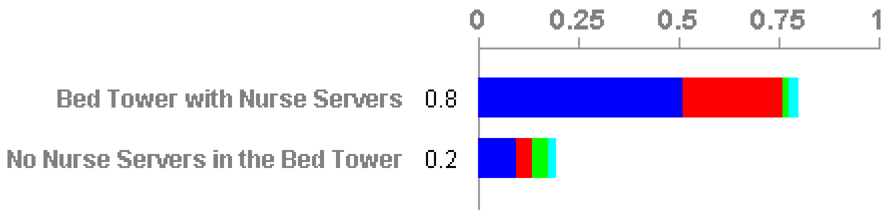
1.10. Barchart Sensitivity

1.10.1. Decision Goal: Provide Nurse Material Support

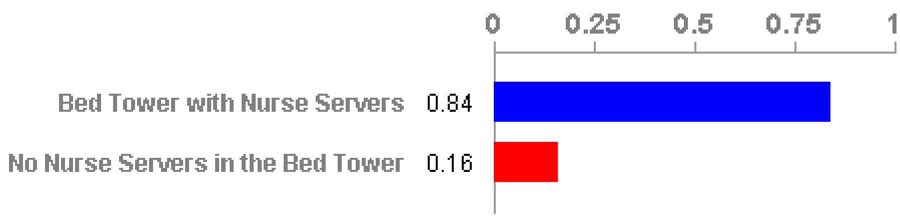
The sensitivity analysis for this node is the following.

Criteria report for Decision Goal: Provide Nurse Material Support

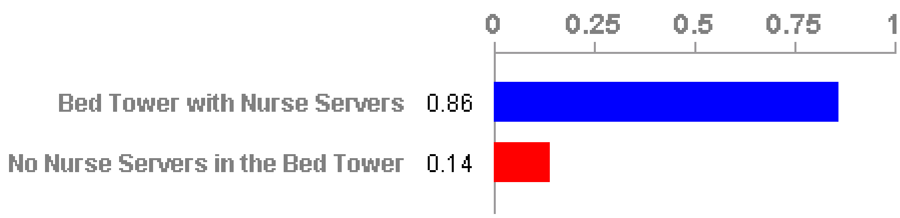




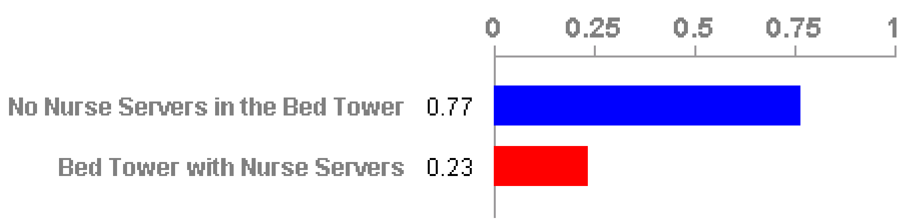
1.10.2. Nursing Response



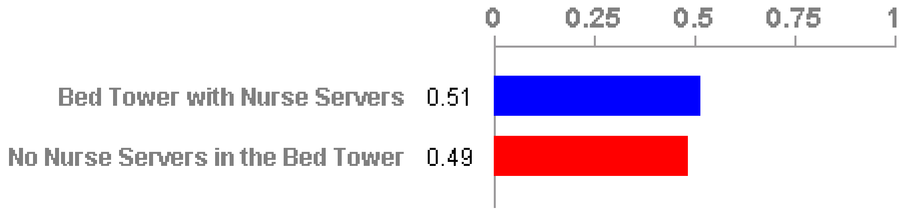
1.10.3. Nursing Staff Efficiency



1.10.4. Materials Management Efficiency



1.10.5. Cost of Additional Supplies


0
0.25
0.5
0.75
1
Bed Tower with Nurse Servers
0.51
No Nurse Servers in the Bed Tower
0.49

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